2010 WHITE RIVER FIELD OFFICE RAPTOR NESTING PRODUCTIVITY AND NEST MONITORING REPORT FOR PICEANCE BASIN, COLORADO

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ABSTRACT

A total of 184 known nesting territories were visited in Piceance Basin (Rio Blanco County, Colorado) during the 2010 breeding season. Of these nest areas, 88% (*n* = 162) were classified as being occupied during the spring surveys, and 11% (*n* = 21) of the known nest areas were confirmed as being unoccupied during the 2010 breeding season. Of the occupied nest areas where the outcome of the nesting attempt was recorded (e.g., failed or successful) (*n* = 124 nests), we reported a success rate of 88% (*n* = 109 successful nests), and a nest failure rate of 12% (*n* = 15 failed nests). The outcome of 38 nesting attempts (*n* = 38 nests or 23% of all occupied nests) was not recorded. Fledging rate information was collected at all nests that successfully fledged young (*n* = 109). These nests produced a total of 310 fledglings ($\bar{x}$ = 2.13, ± 0.32 fledglings produced per successful nest). We found that nest productivity was similar among Cooper's hawk and Long-eared owl in our study area. When considering only successful Cooper's hawk nests (*n* = 49) of 62 possible occupied nests, we found that Cooper's hawk produced on average 3 (± 0.14 fledglings) per breeding pair. Moreover, when considering only successful Long-eared owl nests (*n* = 43) of 59 possible occupied nests, Long-eared owl produced on average 3 (± 0.19 fledglings) per breeding pair. We documented a nest failure rate of 21% for Cooper's hawk (*n* = 13 failed nests) and 27% for Long-eared owl (*n* = 16 failed nests) during the 2010 breeding season. We also noted that nest re-occupancy during the 2010 breeding season was high, with 88% (*n* = 30) of nests that were occupied in 2009 also confirmed as being re-occupied in 2010. When comparing response variable means among active Cooper's hawk (*n* = 62) and Long-eared owl (*n* = 59) nests, we found that Long-eared owl nests were generally located in areas where overall nest density was high (F = 8.22, p = 0.005). We also found that Long-eared owl nests tended to be located closer to neighboring nests when compared to Cooper's hawk nests, which most often were located at further distances from neighboring nests (F = 9.99, p = 0.002). Mean distance from Long-eared owl nests (*n* = 59) to neighboring nests was 362.63 (± 70.25 m), while mean distance from Cooper's hawk nests (*n* = 62) to neighboring nests was 1,129 (± 435.97 m). The mean distance between active Cooper's hawk and Long-eared owl nests was 216 (± 24.9 m, *n* = 27 nest pairs, range = 26 to 515 m), but also recorded three cases where Cooper's hawk and Long-eared owl shared nest stands (mean = 57.3 ± 15.7 m, range = 26 to 74 m). We found that nests that successfully fledged young tended to be closer to other neighboring nests (F = 9.33, p = 0.003). Moreover, twenty-eight (28) percent of all successful nests that were within the 0 to 500 m (*n* = 30) distance categories from a producing well produced 29% (*n* = 90) of all young that were produced during the 2010 breeding season. After calculating the distance from each Cooper's hawk nest that successfully fledged young (*n* = 49) to the nearest producing well, we found that both the maximum number of nests (*n* = 7) and maximum number of young (*n* = 23) produced per distance category were found within the "400 TO 500" distance category. Information collected as a result of this project will contribute to long-term, cumulative efforts to monitor reproductive success, nest site fidelity, better describe important nesting habitat features, and document possible changes in nest distribution and abundance of breeding raptors within the project area that may be impacted by natural gas exploration and extraction activities on BLM-managed lands.

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INTRODUCTION

In April, 2008 the Bureau of Land Management, White River Field Office (WRFO) initiated a project designed to collect breeding season information for woodland raptors in the Piceance Basin, Colorado (T. 1-3 S., R. 96-98 W., 6th Principle Meridian). The purpose of this project was to collect information that would allow for an assessment of nest distribution and territory occupancy over time in areas heavily influenced by natural gas exploration and extraction activities. The target species were Red-tailed hawk (*Buteo jamaicensis*), Cooper's hawk (*Accipiter cooperii*), Sharp-shinned hawk (*Accipiter striatus*), Northern goshawk (*Accipiter gentilis*), Golden eagle (*Aquila chrysaetos*), and Long-eared owl (*Asio otus*).

Project objectives included the following: (1) collect breeding season productivity information for selected raptor species to allow for a robust comparison of differences that may exist, (2) provide both a descriptive and statistical summary of differences in nesting productivity among Cooper's hawk and Long-eared owl in areas where natural gas exploration and extraction activities are prevalent across the landscape.

The purpose and focus of this document is to provide a descriptive summary of results pertaining to nesting success and productivity of various raptor species that occupy the project area during the breeding season for nesting purposes. In addition, the purpose of this document is to provide a statistical comparison, using exploratory, and both parametric and nonparametric statistical tests, to describe observed patterns in nest success and changes in productivity when juxtaposed within a landscape where natural gas exploration and extraction is a dominant feature. For this purpose, and because it was possible to identify discrete features associated with oil and gas activities (e.g., producing wells, well pads, and road infrastructure) we chose to focus our efforts on describing observed distance relationships among Cooper's hawk and Long-eared owl as they pertain to natural gas exploration and extraction, rather than also including possible effects that grazing may have on these species and their prey. A descriptive summary was provided for all species with regard to each response variable; however, because of inadequate sample size, only Long-eared owl and Cooper's hawk were chosen as the two species in which mean difference between response variables were examined statistically.

Assuming adequate funding is available for this project in 2011, the following topics will be included in the project objectives: (1) the continuation of an assessment of possible behavioral effects of oil and gas activities on prey delivery rates, prey diversity and prey equitability, parental behavior, and productivity of Cooper's hawk using video monitoring systems; (2) the development of a sampling scheme that allows for the assessment of detection probability for selected species; (3) the continuation of an assessment of possible cumulative impacts to raptor productivity in areas where natural gas exploration and extraction is relatively localized but intense.

STUDY AREA

The study area is located in northwestern Colorado in the Piceance Basin (T. 1-3 S., R. 96-98 W., 6th Principle Meridian), an area ranging from 1,737 to 2,590 m in elevation (Sedgwick 1987). The dominant overstory vegetation in the area is pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*). Low elevation woodlands on shales are dominated by juniper with an understory of scattered prairie junegrass (*Koleria cristata*), bluebunch wheatgrass (*Agropyron spicatum*), needle-and-thread (*Stipa comata*), bottlebrush squirreltail (*Sitanion hystrix*), Indian ricegrass (*Oryzopsis hymenoides*), and sometimes stunted antelope bitterbrush (*Purshia tridentata*) and true mountain mahogany (*Cercocarpus montanus*). Common forbs include groundsel (*Senecio* spp.), skyrocket gilia (*Gilia aggregata),* penstemon (*Penstemon* spp.), Hood phlox (*Phlox hoodii*), and Nuttall golden weed (*Haplopappus nuttallii*). Pinyon pine, big sagebrush (*Artemisia tridentata*), and western wheatgrass (*A. smithii*) join on sandstone to form a more diverse plant community. Above 2,100 m, pinyon pine is the predominant tree species, and the shrub layer is composed of big sagebrush, rabbitbrush (*Chrysothamnus* spp.), antelope bitterbrush, and occasionally true mountain mahogany, chokecherry (*Prunus virginiana*), and Saskatoon service- berry (*Amelanchier alnifolia*). Gambel oak (*Quercus gambelii*) is prominent on steep slopes and frequently occurs in shady ravines. The grass-forb community above 2,100 m includes most species found at lower elevations, but percentage ground cover is higher; arrowleaf balsamroot (*Balsamorhiza sagittata*) and lupine (*Lupinus* spp.) are also frequently present.

METHODS

Nest Inventory and Monitoring:

Efforts to monitor known nesting territories for the 2010 breeding season began on 26 April and ended on 1 September 2010 within the study area (Figure 1). The start date was defined as the time when field work was conducted full-time by a person dedicated to nest inventory and monitoring tasks, and the end date was chosen as the date when it was confirmed that, of the nests that were being monitored, all accipiter juveniles had dispersed from the nest stand. For list of raptor species codes used throughout this report, see Table 1.

1. Nest Inventory

During the 2008, 2009 and 2010 field season, potential nesting habitat was identified manually using 1 m resolution National Aerial Imagery Program (NAIP) imagery and terrain information (e.g., Digital Elevation Model (DEM) data). Nesting habitat was identified qualitatively based on canopy closure, slope, elevation, dominant cover type, and tree stem density. The validity of using this method to identify potential nesting habitat was confirmed in 2008 and 2009. Qualitative methods used to assess how well this technique identified suitable accipiter nesting habitat were completed in 2009. In addition, canopy closure, slope, elevation, dominant cover type, and tree stem density for accipiter nests (n = 24) that were located by an independent third-party contractor, were compared qualitatively to known accipiter nests (n = 41) to verify that the topographic and nest stand information used to identify potential nesting habitat was reliable. This exercise was also completed in 2009.

In survey polygons, where tree density and canopy cover varied, and where discrete stands that exhibited higher tree density and canopy cover could be visually delineated, call-playback stations were plotted in the interior of these stands, in an effort to increase the observer's probability of detecting an occupied nest through defensive behavior of an adult, or locate unoccupied nests, by focusing the surveyors attention on suitable nesting habitat.

2. Nest Monitoring

Monitoring tasks included visiting known nest areas and assessing the breeding season status of known nests that occurred in these areas using established procedures. Known nest structures were relocated using a Garmin GPS76CSx unit. To help navigate to each nest, the UTM coordinates for each nest was uploaded into the GPS unit using the DNR Garmin version 5.4.1 software. Once at the nest, to help alleviate any discrepancies between the Nest ID number, UTM coordinates and the actual physical location of the nest, a photo was taken of the GPS screen where both the nest ID number and UTM coordinates were displayed. Next, a photo of the nest tree and nest were taken followed by a close-up photo of the nest, and a representative photo of the nest stand (Figure 2). Each series of photos were grouped by the Nest ID number and stored in separate folders using the Nest ID number as the folder name. In some cases, the datum was not recorded for a known nest or was unknown. For these nests, a procedure was developed that included converting UTM coordinates from NAD27 to NAD 83 or vice versa while in the field using the Garmin GPS76CSx unit. For a detailed description of this process, see Smithers (2009). Information collected regarding raptor detections while conducting spring presence/absence surveys was recorded on the "Nest Monitoring and Raptor Detection Data Form", and ongoing monitoring information collected throughout the breeding season was recorded on the "WRFO Nest Monitoring Form" (Smithers 2009).

In addition to on-going efforts to monitor nests, video monitoring systems were used to record behavioral information and document food habits at 7 and 5 occupied Cooper's hawk nests in 2009 and 2010, respectively. Information pertaining to nest success, fledging rates, and dispersal dates were included in this document because of their relevance; however, information pertaining to possible changes in parental behavior and prey utilization will be analyzed separately and will be included in a separate document pending final analysis of these data.

<u>Determining nest status:</u>

Evidence which would suggest a nest had been used during the 2010 breeding season included whitewash under the nest tree or at the roost site, prey remains in the nest stand, down present on the perimeter of the nest, castings under the nest tree, or fresh nesting material on the nest (Smithers 2009). The condition of individual nests was used as a general guide to assess the status of the nest prior to incubation. Occupied nests most often had fresh material (e.g., branches) and tended to appear less compressed or compacted than unoccupied nests. Unoccupied nests tended to have a flattened or compressed appearance , presumably from the effects of snow compacting the nest material during the previous winter (Smithers 2009).

Smithers (2009) also reported that in 2009 at 14 Cooper's hawk nests, regardless of the number of young present in the nest during the brooding, nestling or fledgling phase, because of the amount of residual whitewash that was present under occupied nests, the breeding season status of the nest (i.e., "Occupied" or "Unoccupied") could be confirmed through mid September, 2009, and this pattern was also confirmed during the 2010 breeding season.

For spring surveys and because of limitations in both time and funding for this project, it was decided that emphasis would be placed on documenting whether or not a nest structure was occupied, rather than evaluating whether the nesting territory was occupied. As such, an "occupied" nest structure was defined as a nest where either the adult female was observed incubating eggs, as suggested by the adult being in an incubating posture, or by direct observation of eggs in the nest with the adult bird in the nest stand. A "successful" nest was defined as a nest that produced at least one fledgling. Nests that were determined to be occupied during the spring surveys, and where follow-up surveys indicated that the nest had failed for either known or unknown causes, was classified as a "failed" nest. For our purposes, we define a fledgling as young of the year capable of flying either short distances or capable of sustained flight to and from the nest structure or within the nest area and post-fledgling area (PFA) prior to dispersal from the PFA.

<u>End-of-Season nest status verification:</u>

All accipiter nests that were identified as being occupied during the 2010 spring nest monitoring surveys were visited throughout the breeding season to assess nest status. The primary objective of the end-of-season (EOS) surveys was to determine if nests that were identified as being occupied during the spring surveys successfully produced young. It was determined that mid June would be an appropriate date to assess nest success for those nests that remained occupied throughout the breeding season in 2009 and 2010. The 2010 end-of-season nest status verification involved a two month period which started on 15 June and ended on 20August, where all known nest areas that were identified as being occupied during the spring surveys were visited to access nest success. For those nest areas that remained occupied throughout the breeding season, information pertaining to fledging rates, and fledging and dispersal dates were recorded for each successful nest. The nest status verification start date was chosen to ensure that dispersal of LEOW, RTHA, CORA, and GOEA was also represented, where appropriate. The juveniles of these species typically disperse from the nest stand before juvenile accipiters. A minimum of 2 visits to known active nest structures was required to assess the overall success of each occupied nest area.

3. GIS Analysis

Density analysis:

Density grids were generated using the Spatial Analyst extension in ArcMap (version 9.3.1). The kernel density tool was used to generate density grids for producing well density (PWD), road density (RDD), and nest density (i.e., nest density using all nests, NDEN, nest density using only active nests, ADEN, and nest density using only inactive nests, IDEN). Output grid cell values were set to units per square mile, the search radius was set at 1,609.34 m, and the grid cell size was set at 30 m.

Distance analyses:

For the 2010 distance analyses, using the "near" tool in the proximity toolbox in ArcToolbox (ArcGIS version 9.3.1), four distance measures (e.g., distance from each nest to the nearest producing well (DPW), distance from each nest to the nearest linear feature (DRD), which included pipeline and road corridors, and fence lines, distance between each nest and the closest neighboring nest (DBN), and distance from each nest to the nearest edge of disturbance for well pads (DED), which included both producing and historic well pad locations) were identified, and units are reported in meters.

In addition to calculating distance from a nest to the features listed above, we also summarized the number of nests found within specified distance categories. Distance categories were partitioned into 100 m bands, and the following distance categories were used: 0 to 100, 100 to 200, 200 to 300, 300 to 400, 400 to 500, etc. Because this project was not designed to assess nest site selection in close versus distant proximity to roads and producing wells, and because the data used for this analysis were collected using *a posteriori* methods, we standardize the number of nests found within each distance category by number of nests per hectare. As such, in addition to providing an absolute number for the number of nests recorded within each distance category, we also provide an estimate for nest density, and units are reported in nests per hectare.

4. Data Management

All nest data was entered into the "Inventory" dataset which in its current form is an Excel spreadsheet. This dataset includes all relevant information that has been collected for specific nest structures as part of the WRFO Raptor Inventory and Monitoring Project that was initiated in 2008, and was designed to track nest occupancy, phenological information, changes in species that occupy a given nest structure within a given year, and changes in species that occupy a nest among years. This dataset represents the most reliable location and phenological information available, and this dataset was used for all the analyses included in this document.

5. Statistical Analysis

Sampling units for this project consisted of nests, and nests were opportunistically selected from a sample of all known occupied nests based on accessibility. Thus, nests used in this study were not randomly selected from the population of nests within the study area. All statistical tests were completed using the R statistical software package (R Development Core Team 2005). An alpha of 0.05 was used for all statistical tests (unless noted otherwise), and results are reported as the mean ± SE. For a list and brief description of predictor (i.e., independent) and response (i.e., dependent) variables used in the analyses, see Tables 3 and 4.

<u>Data exploration</u>

Data exploration began with examining the frequency distribution for each variable to visually assess whether or not the data was distributed normally. After visual inspection of the frequency distributions, it was apparent that most of the data were positively skewed to the right of the median. I used the Shapiro-Wilk test procedure to statistically examine which variables did not follow a normal distribution, and the variance of each response variable was tested using Levene's test (Zar 1999).

Data transformation:

Because the data were not distributed normally, and because of my intent to use both parametric and non-parametric test procedures to examine differences among independent variables, the response variables were transformed prior to the analysis. The following transformations were used: Log_{10}, square root, cube root, fourth root and Box-Cox (Table 2). The first step included plotting each transformed variable using the R Commander interface. I then applied the Shapiro-Wilk test procedure to each variable to determine what transformation produced the largest *p* value for the Shapiro-Wilk test statistic, *W*. The resultant transformed response variables were used for all subsequent analyses (Figure 3).

Box-Cox transformation

Using Ecological Methodology 6.1 (Exeter Software, Setauket, NY, USA) and procedures described in Krebs (1999), I used the Box-Cox transformation (Box and Cox 1964) to transform response variables RDD, DPW and DRD. The following equation was used to transform each variable:

$$X' = \frac{X^{\lambda} - 1}{\lambda} \qquad \text{(when } \lambda \neq 0\text{)}$$

The Box-Cox transformation uses the log-likelihood function (*L*) to determine the value of λ that maximizes *L* by calculating values of λ using an iterative process (Box and Cox 1964). Ecological Methodolgy 6.1 (Exeter Software, Setauket, NY, USA) was used to calculate the value of λ, *L*, and the 95% confidence interval for λ for each response variable. The following log-liklihood function was used to calculate values of λ that maximized the value of *L*:

$$L = -\frac{v}{2}\log_e s_T^2 + (\lambda - 1)\frac{v}{n}\sum(\log_e X)$$

where:

L = Value of log-likelihood

v = Number of degrees of freedom (*n* - 1)

s_T^2 = Variance of transformed *X* values

λ = Provisional estimate of power transformation parameter

X = Original data values

Correlation analysis

Using the transformed data, Spearman correlation coefficients and graphs of the variable correlation clusters and correlation matrix were generated using the Rattle Graphical User Interface (GUI) in R.

One-way ANOVA

Using the R Commander GUI in R, I examined differences among response variable means for all nests and the predictor variable STATUS_10, which included 2 levels ("Active" and "Inactive") using a one-way, single factor Analysis of Variance (ANOVA) test procedure (Zarr 1999). Moreover, I examined differences among response variable means and the predictor variable END_10, which included 2 levels ("Successful" and "Failed") using a one-way, single factor ANOVA. Finally, I examined differences among response variable means and the predictor variable SPP_10, which included 2 levels ("COHA" and "LEOW") using a one-way, single factor ANOVA.

Two-way Factorial ANOVA

Using the R Commander GUI in R, I used a two-way factorial ANOVA to examine statistical multiplicative interactions between factor NF_10 (e.g., number of fledglings produced per nest which consisted of 5 levels: 1,2,3,4,5) and factor SPP_10 (two levels: COHA and LEOW) (Zarr 1999). Moreover, I used a two-way factorial ANOVA to examine statistical multiplicative interactions between factor END_10 (i.e., whether the nest successfully produced young or whether the nest failed and consisting of 2 levels: "SUCCESSFUL" and "FAILED") and factor SPP_10 (two levels: COHA and LEOW). A factorial design was selected to try and reduce the unexplained (or residual) variation in the response variable, and to examine possible interactions between factors, i.e., whether the effect of a particular factor on the response variable is dependent on another factor (Quinn and Keough 2002).

Goodness-of-fit Tests for Association

I used a goodness-of-fit (e.g., Chi-square test) to examine differences in both the number of nests recorded within specific distance categories from each response variable and the number of young produced. The chi-square value (χ^2), degrees of freedom (*df*), and the value of *p* were calculated using an interactive chi-square calculation tool that was developed by Preacher (2001) and is available on-line at http://www.people.ku.edu/~preacher/chisq/chisq.htm.

RESULTS

Nest Monitoring

A total of 183 known nesting territories were visited during the 2010 field season. Of these nest areas, 88% (n = 162) were classified as being occupied during the spring surveys, and 11% (n = 21) of the known nest areas were confirmed as being unoccupied during the 2010 breeding season. Of the occupied nest areas where the outcome of the nesting attempt was recorded (e.g., failed or successful) (n = 124 nests), we reported a success rate of 88% (n = 109 successful nests), and a nest failure rate of 12% (n = 15 failed nests). The outcome of 38 nesting attempts (n = 38 nests or 23% of all occupied nests) was not recorded. Fledging rate information was collected at all nests that successfully fledged young (n = 109). These nests produced a total of 310 fledglings ($\bar{x}$ = 2.13, ± 0.32 fledglings produced per successful nest).

We found that nest productivity was similar among Cooper's hawk and Long-eared owl in our study area. When considering only successful Cooper's hawk (n = 49) nests of 62 possible occupied nests, we found that Cooper's hawk produced on average 3 (± 0.14 fledglings) per breeding pair (Table 5). When considering only successful Long-eared owl nests (n = 43) of 59 possible occupied nests, Long-eared owl produced on average 3 (± 0.19 fledglings) per breeding pair. We documented a nest failure rate of 21 % for Cooper's hawk (n = 13 failed nests) and 27 % for Long-eared owl (n = 16 failed nests) during the 2010 breeding season.

A total of 46 nests representing 33% of all nests visited in 2009 (n = 139) were visited in 2010. Moreover, thirty-four (57%) of the 2009 nests that were active in 2009 (n = 60) were visited in 2010. We noted that nest re-occupancy during the 2010 breeding season was high, with 88% (n = 30) of nest that were occupied in 2009 also being reoccupied in 2010. Eight percent (n = 3) of the nests that were active in 2009 were determined to be inactive in 2010.

Twelve of the nests that failed in 2009 were visited in 2010, and of these nests, 67% (n = 8) successfully produced young during the 2010 breeding season.

Correlation analysis

Correlation analysis for all species:

When considering data for all nests and all species, there were no unexplained or unanticipated statistically significant correlations between the response variable combinations (Figures 4 and 7, Table 6).

Statistically significant correlations that could be explained fairly easily included the relationship between distance between nests (DBN) and nest density (NDEN). As predicted, as nest density increased, the distance between nests decreased (r_s = 0.72). Moreover, as distance from a nest to the nearest edge of disturbance (DED) increased, the distance to a producing well (DPW) also increased (r_s = 0.61). This correlation provides support for our assumption that most disturbance features in the project area, excluding linear pipeline corridors, are natural gas well pads.

Correlations that were unexpected, though not statistically significant, included the relationship between percent slope (SLP) and distance to the nearest edge of disturbance (DED). As slope increased, the distance from a nest to the nearest edge of disturbance also increased (r_s = 0.22).

In addition, we also identified a weak correlation between producing well density (PWD) and distance to the nearest edge of disturbance (DED) (r_s = 0.27). Nests that occurred in areas where producing well density was high were farther away from disturbance features (e.g., natural gas well pads), which was also contrary to what was expected.

There also appeared to be a weak correlation between the distance from a nest to the nearest natural gas producing well (DPW) and distance from a nest to the next adjacent nest (DBN) (r_s = 0.28). As distance between nests increased, the distance from a nest to the nearest producing well also increased (i.e., nests that were located in areas where nest density was high also tended to be closer to producing wells).

Correlation analysis for occupied and unoccupied nests:

When considering only active nests for correlation analyses, there were no unexplained or unanticipated statistically significant correlations between the response variable combinations (Figures 5 and 8, Table 7).

Similar to the correlation between distance between nests (DBN) and nest density (NDEN) when all nests were included in correlation analyses, variables DBN and ADEN (active nest density) were statistically correlated ($r_s = 0.60$) when only data for active nests were used for correlation analyses. In addition, distance from nests to the nearest edge of disturbance (DED) and distance from nests to the nearest producing well (DPW) were also correlated ($r_s = 0.58$).

When considering only data for inactive nests for correlation analyses, similar to results generated for “all nests” and for “active nests”, there were no unexpected correlations between response variable (Figures 5 and 9, Table 7). Variables DPW (distance to a producing well) and DED (distance to the nearest edge of disturbance) were statistically correlated ($r_s = 0.83$). Moreover, variables PWD (producing well density) and DED (distance to the nearest edge of disturbance) ($r_s = 0.68$), and PWD and DPW were also correlated ($r_s = 0.71$).

Correlation analysis for Cooper’s hawk and Long-eared owl:

Similar to the correlation between DBN (distance between nests) and NDEN (nest density) when all nests were included in correlation analyses, variables DBN and ADEN (active nest density) and DBN and NDEN were statistically correlated ($r_s = 0.72$, 0.81, respectively) when only data for COHA nests were used for correlation analyses (Figures 6 and 10, Table 8). Moreover, distance from nests to the nearest edge of disturbance (DED) and distance from nests to the nearest producing well (DPW) were also correlated ($r_s = 0.48$).

Unexpected was the correlation between slope (SLP) and active nest density (ADEN) when using only data for active Cooper’s hawk nests. As slope increased, active nest density also increased ($r_s = 0.46$). Cooper’s hawk nests that occurred in areas where active nest density was high also tended of have higher slope values.

Similar to the correlation between DBN and NDEN when all nests were included in correlation analyses, variables DBN and NDEN were statistically correlated ($r_s = 0.41$) when only data for Long-eared owl nests were used for correlation analyses (Figures 6 and 11, Table

8). Moreover, distance from nests to the nearest edge of disturbance (DED) and distance from nests to the nearest producing well (DPW) were also correlated ($r_s = 0.63$).

Unexpected was the correlation between elevation (ELEV) and active nest density (ADEN) when using only data for active Long-eared owl nests. As elevation increased, active nest density also increased ($r_s = 0.52$). Long-eared owl nests that occurred at higher elevations were located closer together.

One-way ANOVA

We found that there was no statistical difference among active (n = 162) and inactive nests (n = 21) when comparing their proximity to linear features (DRD) (F = 3.51, p = 0.06, Table 9). On average, active nests were 225.47 (± 14.28 m) and inactive nests were 302.96 (± 50.40 m) from a linear feature (Table 10). Moreover, when comparing response variable means among failed (n = 15) and successful nests (n = 109), we found no statistical difference among nest success (e.g., failed or successful) and producing well density (F = 3.67, p = 0.06, Table 11). On average, successful nests were located in areas where mean producing well density equaled 2.97 (± 0.45 wells/mi^2), and failed nests were located in areas where mean producing well density equaled 1.07 (± 0.29 wells/mi^2) (Table 12). When comparing response variable means among active Cooper's hawk (n = 62) and Long-eared owl (n = 59) nests, we found that Long-eared owl nests were generally located in areas where overall nest density was high (F = 8.22, p = 0.005) when compared to Cooper's hawk (Figure 12, Table 13). Mean nest density at Long-eared owl nest sites was 3.46 (± 0.20) nests/mi^2, while mean nest density at Cooper's hawk nest sites was 2.69 (± 0.16 nests/mi^2) (Table 14). We did find that Long-eared owl nests tended to be located closer to other neighboring nests when compared to Cooper's hawk nests, which most often were located at farther distances from neighboring nests (F = 9.99, p = 0.002) (Figure 12, Table 13). Mean distance from Long-eared owl nests (n = 59) to neighboring nests was 362.63 (± 70.25 m), while mean distance from Cooper's hawk nests (n = 62) to neighboring nests was 1,129 (± 435.97 m) (Table 14).

Two-way Factorial ANOVA

Two-way factorial ANOVA results showed that the number of young that successfully fledged at nests close to linear features did not vary among Cooper's hawk and Long-eared owl successful nests ($F = 2.37$, $p = 0.06$, Figure 13).

There appeared to be no statistical difference between the number of young produced at occupied Long-eared owl and Cooper's hawk nests in areas where nest density was high ($F = 3.79$, $p = 0.06$). However, we did observe a statistical difference in response variable means among successful and failed nests and distance to neighboring nests (DBN) ($F = 9.33$, $p = 0.003$) (Figure 14). Nests that successfully fledged young tended to be closer to other neighboring nests.

Though not statistically significant, Cooper's hawk tended to be more productive in areas where producing well density was low (i.e., more fledglings were produced in areas where producing well density was low); however, there were more successful nests in areas where producing well density was high versus areas where producing well density was low; fledging rates were simply lower in these areas. Moreover, factorial ANOVA results showed that there was interaction between SPP_10 and NF_10 for analyses using producing well density as the response variable ($F = 2.85$, $p = 0.03$).

Productivity results and distance measures:

Because of inadequate sample size, distance analyses results presented in this section were limited to Cooper's hawk (COHA) and Long-eared owl (LEOW). Moreover, because of their relevance to oil and gas operations that occur in the project area, distance to producing wells (DPW), distance to roads (DRD), and distance to the nearest edge of disturbance (DED) were chosen as the variables that would be reported here. If necessary, the reader can refer to Table 14 for disturbance-related results for all raptor species and all variables that were included in the analysis.

<u>Distance from a producing well (DPW) for all species:</u>

In our project area we found that nests were most numerous within a distance band of 400 to 500 m from a producing well (Table 15). Successful nests within this category ($n = 12$) produced 11% ($n = 35$) of all young produced ($n = 310$) during the 2010 breeding season. On average, 2.92 (± 0.29 fledglings) were produced per nest within this distance category from a producing well. We did observe a pattern in which both the number of successful nests recorded (χ^2 = 10.7, *df* = 4, *p* = 0.03) and the number of fledglings produced increased as distance from the nest to a producing well increased (χ^2 = 30.2, *df* = 4, *p* < 0.0001, Table 15) within 500 m of a producing well. We found that 28% of all successful nests that were within the 0 to 500 m (*n* = 30) distance categories from a producing well produced 29% (*n* = 90) of all young that were produced during the 2010 breeding season.

<u>Distance from travel corridor (DRD) for all species:</u>

We found that nests that successfully produced young were generally located closer to roads when compared to the proximity of a nest to a producing well, and both number of nests (χ^2 = 18.2, *df* = 4, *p* = 0.001), and the number of young produced within each distance category decreased at farther distances from a road (χ^2 = 62.8, *df* = 4, *p* = 0.00001) (Table 16) within 500 m of a road. We found that both the maximum number of nests (*n* = 31, 9.9 nests per ha) and maximum number of young produced occurred within the "100 TO 200" distance category. Within this distance category we recorded 31 nests which represented 29% of all successful nests (*n* = 108), producing 95 young (31%). On average, 3.06 (± 0.21 fledglings) were produced per nest within this distance category.

<u>Distance from the nearest edge of disturbance (DED) for all species:</u>

Both the maximum number of nests (*n* = 17, 1.8 nests per ha) and maximum number of young produced per distance category were found within 300 to 400 m from the nearest edge of disturbance (DED) (Table 17). This distance category produced 46 young (*n* = 17 nests), with a mean number of young produced per nest equal to 2.71 (± 0.24). It should also be noted that the frequency distribution of young produced within distance categories 0 TO 100 (*n* = 30), 100 TO 200 (*n* = 35), 200 TO 300 (*n* = 45), and 300 TO 400 (*n* = 46) were equitably distributed (χ^2 = 2.0, *df* = 3, *p* = 0.60), with a mean value equal to 39 (± 3.90 young produced per distance category) (Table 17). Moreover, the frequency distribution for the number of nests within each distance category from the nearest edge of disturbance (DED) was equitably distributed from 0 to 400 m from the nearest edge of disturbance (χ^2 = 4.7, *df* = 3, *p* = 0.20), and we did not observe any statistical pattern that would suggest ether the number of nests or the number of young produced within each distance category at nests that were located close to a disturbance feature versus those nests that were located at greater distances from a disturbance feature.

Distance from a producing well (DPW) for Cooper's hawk and Long-eared owl:

After calculating the distance from each Cooper's hawk nest that successfully fledged young (n = 49) to the nearest producing well, we found that both the maximum number of nests (n = 7, 0.15 nests per ha) and maximum number of young (n = 23) produced per distance category were found within the "400 TO 500" distance category (Table 18). The mean number of Cooper's hawk young produced per nest within this distance category was 3.29 (± 0.29 young). Moreover, we found that 35% (n = 17) of all Cooper's hawk nests recorded that successfully fledged young were within 500 m from a producing well. These nests produced 37% (n = 54) of all Cooper's hawk young that fledged (n = 147) during the 2010 breeding season in our study area. As noted above, we did observe a general trend that suggests Cooper's hawk productivity was higher at nests that were located farther from a producing well (i.e., within the 400 TO 500 distance category) when compared to nests that were located closer to a producing well (Table 18). When examining the frequency distribution of Cooper's hawk young produced within distance categories 0 TO 100 (n = 4), 100 TO 200 (n = 3), 200 TO 300 (n = 11), 300 TO 400 (n = 13), and 400 TO 500 (n = 23), inspection of these data show that they were not equitably distributed (χ^2 = 24.1, df = 4, $p < 0.0001$), with a mean equal to 10.8 (± 3.60 young produced per distance category) (Table 18). We also found that the frequency of young produced per distance category varied among Cooper's hawk and Long-eared owl nests (χ^2 = 14.4, df = 3, p = 0.002) (Table 18). We documented only one successful Cooper's hawk nests within 100 m of a producing well; however, this nest produced 4 young.

After calculating the distance from each Long-eared owl nest that successfully fledged young (n = 42) to the nearest producing well, we found that the maximum number of nests (n = 6, 0.07 nests per ha) were found within the "600 TO 700" distance category, while the maximum number of young produced (n = 20) were found within the 900 TO 1000 distance category. The mean number of Long-eared owls produced per nest within this distance category was 4 young (± 0.71). We also found that twenty-six percent (n = 11) of all successful nests occurred within 500 m from a producing well. These nests produced 25% (n = 32) of all Long-eared owl young that survived to fledge (n = 126) during the 2010 breeding season in our study area. Unlike

Cooper's hawk, both the number of young produced ($\chi^2 = 7.75$, $df = 3$, $p = 0.05$), and the number of nests within each distance category varied at nests farther away from a producing well when compared to nests that were closer to a producing well ($\chi^2 = 2.5$, $df = 3$, $p = 0.48$). We did not document any successful Long-eared owl nests within 100 m of a producing well.

<u>Distance from linear features (DRD) for Cooper's hawk and Long-eared owl:</u>

After calculating the distance from each Cooper's hawk nest that successfully fledged young ($n = 49$) to the nearest road, we found that both the maximum number of nests ($n = 15$, 1.6 nests per ha) and maximum number of young ($n = 46$) produced per distance category were found within the "100 TO 200" distance category (Table 19). The mean number of Cooper's hawk young produced per nest within this distance category was 3.07 (± 0.21 young). We also recorded 13 successful Cooper's nests occurring within 100 m of a road. These nests produced 44 young with a mean value equal to 3.38 (± 0.24) young produced per nest. We also found that the frequency of nests ($\chi^2 = 24.9$, $df = 6$, $p < 0.001$) and the number of young produced within each distance category decreased within 700 m of a road ($\chi^2 = 84.23$, $df = 6$, $p < 0.0001$).

We observed similar results when examining distance from successful Long-eared owl nests to the nearest road. Of all successful Long-eared owl nests that we recorded ($n = 42$), we found that the maximum number of nests were found in both the 0 TO 100 ($n = 12$, 3.82 nests per ha) and the 100 to 200 ($n = 12$, 1.27 nests per ha) distance categories (Table 19). We also recorded the maximum number of young ($n = 42$) produced per distance category were found within the "100 TO 200" distance category. The mean number of Long-eared owl young produced per nest within this distance category was 3.50 (± 0.38 young). As noted above, we recorded 12 successful Long-eared owl nests within 100 m of a road. These nests produced 29 young with a mean value equal to 2.42 (± 1.16) young produced per nest. Similar to Cooper's hawk, we found that the number of young produced within 500 m of a road generally decreased at farther distances from a road ($\chi^2 = 25.8$, $df = 4$, $p < 0.0001$) (Table 19). However, the frequency of nests within each distance category within 500 m of a road appeared to be equitably distributed ($\chi^2 = 8$, $df = 4$, $p = 0.09$). We also found that the frequency of nests ($\chi^2 = 24.9$, $df = 6$, $p < 0.001$) and the number of young produced within each distance category decreased within 700 m of a road ($\chi^2 = 84.23$, $df = 6$, $p < 0.00001$).

Distance from edge of disturbance (DED) for Cooper's hawk and Long-eared owl:

After calculating the distance from each Cooper's hawk nest that successfully fledged young (n = 49) to the nearest edge of disturbance (DED), we found that both the maximum number of nests (n = 12, 0.38 nests per ha) and maximum number of young (n = 34) produced per distance category were found within the "300 TO 400" distance category (Table 20). The mean number of Cooper's hawk young produced per nest within this distance category was 2.83 (± 0.94 young). We also recorded 5 successful Cooper's nests occurring within 100 m of a natural gas well pad. These nests produced 14 young with a mean value equal to 2.80 (± 1.30) young produced per nest. When examining the frequency distribution of Cooper's hawk young produced within distance categories 0 TO 100 (n = 14, 4.50 nests per ha), 100 TO 200 (n = 13, 1.38 nests per ha), 200 TO 300 (n = 26, 1.38 nests per ha), and 300 TO 400 (n = 34, 1.08 nests per ha), inspection of these data show that they were not equitably distributed (χ^2 = 14.01, df = 3, p = 0.003), with a mean equal to 21.75 (± 5.04 young produced per distance category) (Table 20).

After calculating the distance from each Long-eared owl nest that successfully fledged young (n = 42) to the nearest edge of disturbance (DED), we found that both the maximum number of nests (n = 6, 0.09 nests per ha) and maximum number of young (n = 19) produced per distance category were found within the "500 TO 600" distance category (Table 20). The mean number of Long-eared owl young produced per nest within this distance category was 3.17 (± 0.60 young). We recorded 5 successful Long-eared owl nests occurring within 100 m of a natural gas well pad. These nests produced 16 young with a mean value equal to 3.20 (± 0.84) young produced per nest. It should also be noted that, unlike Cooper's hawk, the frequency distribution of young produced within distance categories 0 TO 100 (n = 16, 5.10 nests per ha 100 TO 200 (n = 16, 1.70 nests per ha), 200 TO 300 (n = 13, 0.69 nests per ha), and 300 TO 400 (n = 9, 0.29 nests per ha), 400 TO 500 (n = 14, 0.30 nests per ha), and 500 TO 600 (n = 19, 0.29 nests per ha) were equitably distributed (χ^2 = 3.97, df = 5, p > 0.05) with a mean value equal to 14.5 (± 1.38 young produced per distance category).

DISCUSSION

Raptor productivity and nest success appeared to be high during the 2010 breeding season in our study area. A total of 184 known nesting territories were visited during the 2010 field season. Of these nest areas, 88% (n = 162) were classified as being occupied during the spring surveys, and 11% (n = 21) of the known nest areas were confirmed as being unoccupied during the 2010 breeding season. Of the nest areas that were classified as occupied in 2010, 67% (n = 109) of these nest areas successfully fledged young, producing a total of 310 fledglings ($\bar{x}$ = 2.13 ± 0.32 fledglings produced per successful nest per species). We reported a nest failure rate of 9% (n = 15) during the 2010 breeding season. We also noted that nesting area re-occupancy during the 2010 breeding season was high, with 88% (n = 30) of these nest areas that were occupied in 2009 also being re-occupied in 2010.

We found that nest productivity was similar among Cooper's hawk and Long-eared owl in our study area. When considering only successful Cooper's hawk (n = 49) nests of 62 possible occupied nests, we found that Cooper's hawk produced on average 3 (± 0.14 fledglings) per breeding pair. When considering only successful Long-eared owl nests (n = 43) of 59 possible occupied nests, Long-eared owl produced on average 3 (± 0.19 fledglings) per breeding pair. We documented a nest failure rate of 21% for Cooper's hawk (n = 13 failed nests) and 27% for Long-eared owl (n = 16 failed nests).

High prey densities and mild weather were most likely key proximate factors affecting nesting productivity and nest success during the 2010 breeding season in our study area. Within the project area, the Colorado Division of Wildlife (CDOW) and BLM conducted small mammal inventory projects designed to document small mammal densities (Neubaum and Belmonte, personal communication). These projects found that small mammal densities were high, with density values in the project area ranging from 36 to 54 (n = 6 sampling locations, $\bar{x}$ = 47± 2.97 individuals per hectare). Small mammal diversity was relatively low, with deer mouse (n = 588) and least chipmunk (n = 96) serving as the dominant species captured. The results of both projects most likely apply more directly to Long-eared owl rather than Cooper's hawk because sampling techniques resulted in the capture and identification of smaller prey that are typically more active at night.

An additional piece of behavioral information collected through video monitoring of occupied Cooper's hawk nests that provides anecdotal evidence for high prey abundance in the study area includes the fact that adult Cooper's hawk females appeared to spend more time in the nest stand and more time at the nest tending to nestlings. In Arizona, Dewey and Kennedy (2001) also reported more time spent in the nest stand by adult female goshawks at nests that were supplemented with additional food. We also consistently documented excess prey (i.e., unconsumed prey left alone for extended periods of time) either on the rim of the nest or under the nest at 8 (5 %) of all occupied nests monitored in 2010. Lastly, there were no confirmed cases of mammalian (e.g., bobcat) depredation at any active nests in 2010, presumably because bobcat were most likely preying on more abundant and more available alternative prey.

Food habits of Cooper's hawks during the breeding season have been well documented (Bielefeldt and Rosenfield 1992, Kennedy 1980, Kennedy and Johnson 1986, Kennedy et al. 1991, Reynolds and Meslow 1984, Snyder and Snyder 1973). The diets of Cooper's hawks are diverse and vary geographically but in general, the most common prey are mid-sized birds and mammals that forage primarily on the ground (Rosenfield and Bielefeldt 1993). Bielefeldt and Rosenfield (1992) monitored prey deliveries by adults to nestlings at nests in forested areas and at nests in semi-urban areas in Wisconsin and found that eastern chipmunks (*Tamias striatus*) were strongly the predominant mammalian items delivered to all nests. Moreover, they found that prey that forage primarily or frequently on the ground accounted for nearly all of the mammalian and avian prey items. Cooper's hawks in Oregon also foraged primarily near the ground, and Reynolds and Meslow (1984) found that chipmunks and brush rabbits (*Sylvilagus* spp.) were the most common mammalian prey taken. In North Dakota, Peterson and Murphy (1992) observed that the most frequently delivered prey were between 9 – 70 g. Thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*) contributed most (23%) as a species to biomass while mice were the most common (13.5%) mammalian prey items.

Within our study area, other than the confounding effects that seasonal weather patterns may have on prey abundance, the creation of natural gas exploration and extraction infrastructure and the cumulative loss of pinion-juniper woodland and conversion to early seral, grass and shrub dominated communities are presumed to be the dominant factors that may affect the distribution of both prey and raptor species in or study area. Creation of these features result in a landscape that generally exhibits increased woodland, shrub, and non-woodland patch shape complexity, decreased woodland patch size, an increase in the amount of edge between open areas and woodlands, and an increase in patch density. With an increase in patch edge, and an increase in the number of open areas, Cooper's hawk and Long-eared owl may utilize both edge and open areas disproportionately to what is available to forage. The edge/clearing interface presumably may provide Cooper's hawk more opportunities to chase and catch both avian and mammalian prey. In central Sweden, Kenward (1982) found that 4 radio tagged male Finnish goshawks spent 50% of their time foraging within 200 m of the edge/clearing interface. Moreover, most of the recorded kills were made in woodland within 200 m of a clearing. Kenward (1982) also noted that range size was related to the proportion of range that was woodland edge, and to prey availability. Because Cooper's hawk in our study area may have more opportunities to catch and kill avian and mammalian prey in the edge/clearing interface, they may also be spending a disproportionate amount of time foraging in open areas and along the edge/clearing interface securing prey items.

Though the results are preliminary, results from the 2009 and 2010 video monitoring project suggest that Cooper's hawk rely heavily on small mammals to provision their young during the breeding season (Smithers 2010). Moreover, as mentioned above, the degree to which the project area has been impacted by natural gas exploration and extraction and the removal of cumulatively large areas of Pinion-juniper woodlands, replaced by early seral species of grasses and shrubs, and the preponderance of small mammals in the diet (e.g., ground squirrels and chipmunks) that are more abundant and accessible in open areas and along forest edges, may explain why Cooper's hawk are foraging more heavily on these species. In our study area, O'Meara et al. (1981) found that small mammals were more abundant in areas that were disturbed as a result of chaining; however, they also noted that species diversity was lower in treated areas versus untreated areas. Oil and gas activities in the project area may provide similar disturbance features that help increase small mammal abundance per unit area, though decrease overall small mammal diversity as a result of mechanically removing pinyon-juniper woodlands.

When examining possible correlations between response variables, unexpected was the correlation between elevation (ELEV) and active nest density (ADEN) when using only data for active Long-eared owl nests. As elevation increased, active nest density also increased (r_s = 0.52). Long-eared owl nests that occurred at higher elevations were located closer together. One plausible explanation might be that food resources may be more abundant and available at higher elevations, which in this case would be Pinion-juniper communities at 6,800 feet in elevation. This explanation could also be used to explain Long-eared owls nesting in close proximity to other active nests because there is less competition for food resources, and possibly less effects from territoriality. Yet another explanation might be that because, as a group, Long-eared owl nests found in the Magnolia area exhibit both higher nest densities and occur at higher elevations when compared to other occupied Long-eared owl nests in the study area. Yet another possible explanation could rely on the fact that nests that were found at higher elevations also tended to occur in areas where the influence of steep topography and sheltering of nests from neighboring occupied nests resulted in more nests per unit area. If this hypothesis is true, higher nesting densities would be recorded in areas where topography is more course, as measured by a higher degree of steep slopes per unit area.

When comparing response variable means among active (n = 162) and inactive nests (n = 21), we found that there was no statistical difference among active and inactive nests when comparing their proximity to linear features (DRD) ($F = 3.51$, $p = 0.06$). On average, active nests were 225.47 (± 14.28 m) and inactive nests were 302.96 (± 50.40 m) from a linear feature. Even though we did not find a statistical difference among active and inactive nests and distance to linear features, and even though we have no reason to believe that a difference of 78 m from either active or inactive nests to a linear feature holds any biological significance, we do feel that linear features may serve as important features within the landscape that provide additional foraging opportunities for both Long-eared owl and Cooper's hawk. For both Long-eared owl and Cooper's hawk, linear two-tracks or cleared areas associated with fence lines, pipeline corridors and reclaimed road shoulders may provide more foraging opportunities by creating an area where both prey availability and prey abundance is higher versus areas within forested woodlands.

There appeared to be no statistical difference between the number of young produced at occupied Long-eared owl and Cooper's hawk nests in areas where nest density was high (F = 3.79, $p = 0.06$). However, we did observe a statistical difference in response variable means among successful and failed nests and distance to neighboring nests (DBN) ($F = 9.33$, p = 0.003). Nests that successfully fledged young tended to be closer to other neighboring nests. In addition, Long-eared owl nests also tended to be located closer to other nests when compared to

Cooper's hawk nests, which most often were located at farther distances from neighboring nests ($F = 9.99$, $p = 0.002$). Mean distance from occupied Long-eared owl nests ($n = 59$) to neighboring nests was 362.63 (± 70.25 m), while mean distance from occupied Cooper's hawk nests ($n = 62$) to neighboring nests was 1,129 (± 435.97 m). As mentioned above, the fact that occupied Long-eared owl nests were located closer to neighboring nests could possibly be explained by the fact that Long-eared owl tended to occupy nests in close proximity to alternate nest structures, when compared to Cooper's hawk. In addition, Long-eared owl may be less territorial than Cooper's hawk during the breeding season, especially in years when prey are readily available. We did find 3 cases where both Cooper's hawk and Long-eared owl occupied the same nest stand. In these cases, distance from each occupied Cooper's hawk and Long-eared owl nest within a single nest stand ranged from 26 to 74 meters (mean = 57.3 ± 15.7). We also noted that the mean distance between active Cooper's hawk and Long-eared owl nests was 216 (± 24.9 m, $n = 27$ nest pairs, range = 26 to 515 m). In addition, we found there was considerable overlap between Long-eared owl and Cooper's hawk with respect to nest tree dbh, nest tree species, canopy closure within the nest stand, and mean tree height within the nest stand.

Though not statistically significant, Cooper's hawk tended to be more productive in areas where producing well density was low (i.e., more fledglings were produced in areas where producing well density was low); however, there were more successful nests in areas where producing well density was high versus areas where producing well density was low; fledging rates were simply lower in these areas. We also observed a numerical pattern in which both the number of successful nests recorded ($\chi^2 = 10.7$, $df = 4$, $p = 0.03$) and the number of fledglings produced increased as distance from the nest to a producing well increased ($\chi^2 = 30.2$, $df = 4$, $p < 0.0001$), and this pattern extending from the nest out to 500 m from a producing well.

As noted above, we did observe a general trend that suggests Cooper's hawk productivity was higher at nests that were located farther from a producing well, and that the maximum number of young fledged was found at nests that were within the 400 to 500 m from a producing well. After calculating the distance from each Cooper's hawk nest that successfully fledged young ($n = 49$) to the nearest producing well, we found that both the maximum number of nests ($n = 7$, 0.15 nests per ha) and maximum number of young ($n = 23$) produced per distance category were found within the "400 TO 500" distance category. The mean number of Cooper's hawk young produced per nest within this distance category was 3.29 (± 0.29 young).

Assuming adequate funding is available for this project in 2011, the following topics will be included in the project objectives for 2010: (1) the continuation of an assessment of possible behavioral effects of oil and gas activities on prey delivery rates, prey diversity and prey equitability, parental behavior, and productivity of Cooper's hawk using video monitoring systems; (2) the development of a sampling scheme that allows for the assessment of detection probability for selected species; and (3) the continuation of an assessment of possible cumulative impacts to raptor productivity in areas where both producing well density and road density is high.

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Table 1. The following table includes a list species' codes used throughout this document.

Species	Code
American kestrel	AMKE
Bald eagle	BAEA
Cooper's hawk	COHA
Common raven	CORA
Great-horned owl	GHOW
Golden eagle	GOEA
Long-eared owl	LEOW
Northern goshawk	NOGH
Peregrine Falcon	PEFA
Prairie falcon	PRFA
Red-tailed hawk	RTHA
Sharp-shinned hawk	SSHA
Northern saw-whet owl	SWOW
Unknown species	UNK

Table 2. The following table shows the type of transformation that was performed on each variable. See Figure 3 for resultant frequency distribution curves using the transformation identified below. Data used in this project was collected throughout the study area during the 2010 breeding season in Piceance Basin, Colorado.

Variable	Transformation	Transformed Variable
PWD	Power transformation using the fourth root of each observation (i.e., $x^{0.25}$)	FOURTH_PWD
RDD	Box-Cox transformation using a lambda of 0.687	BC_RDD
ELEVATION	Log transformation using the Log_{10} of each observation and adding 1	LOG_ELEV
ASPECT	Log transformation using the Log_{10} of each observation and adding 1	LOG_ASPECT
SLP	Log transformation using the Log_{10} of each observation and adding 1	LOG_SLP
NEST_DEN	Power transformation using the square root of each observation (i.e., $x^{0.5}$)	SQRT_NEST_DEN
ACT_DEN	Power transformation using the cube root of each observation (i.e., $x^{0.33}$)	CUBE_ACT_DEN
IA_DEN	Log transformation using the Log_{10} of each observation and adding 1	LOG_IA_DEN
DIST_M	Log transformation using the Log_{10} of each observation and adding 1	LOG_DIST_M
DPW	Box-Cox transformation using a lambda of 0.109	BC_DPW
DRD	Box-Cox transformation using a lambda of 0.229	BC_DRD
SURF_DIST	Log transformation using the Log_{10} of each observation and adding 1	FOURTH_SURF_DIST

Table 3. The following table provides variable codes and variable descriptions for the independent (i.e., explanatory or predictor) variables used in statistical analyses.

Variable Name	Description
SPP_10	Species documented using the nest during the 2010 breeding season.
STATUS_10	The 2010 breeding season status of the nest (e.g., "ACTIVE", "INACTIVE", "UNKNOWN")
END_10	The 2010 end status of the nest (e.g., "SUCCESSFUL", "FAILED", UNKNOWN")
NF_10	The number of young that fledged from the nest during the 2010 breeding season.
RANK_PWD	The density ranking grouped by number of nests with producing well density values ranging from 0 to 1, 1 to 2, 2 to 3, etc. producing wells per square mile
RANK_RDD	The density ranking grouped by number of nests with road density values ranging from 0 to 1, 1 to 2, 2 to 3, etc. miles of road per square mile.
RANK_DIST_NEST	The distance ranking grouped by number of nests within 0 to 100 m, 100 to 200 m, 200 to 300 m , 300 to 400 m, etc. of another nest.
RANK_DPW	The distance ranking grouped by number of nests within 0 to 100 m, 100 to 200 m, 200 to 300 m , 300 to 400 m, etc. of the nearest producing well.
RANK_DRD	The distance ranking grouped by number of nests within 0 to 100 m, 100 to 200 m, 200 to 300 m , 300 to 400 m, etc. of the nearest linear feature.
RANK_SURF_D	The distance ranking grouped by number of nests within 0 to 100 m, 100 to 200 m, 200 to 300 m , 300 to 400 m, etc. to the nearest edge of disturbance for anthropogenic disturbance features.

Table 4. The following table provides variable codes and variable descriptions for the dependent (i.e., response) variables used in statistical analyses.

Variable Name	Description
PWD_SQMI	Producing well density. Producing well density grid cell values were extracted to each nest.
RDD	Road density. Road density grid cell values were extracted to each nest.
NEST_DEN	Nest density. Using all nests (i.e., Active, Inactive, Unknown), nest density values were extracted to each nest.
ACT_DEN	Active nest density. Using only "Active" nests to create the nest density grid, density grid cell values were extracted to each nest.
INACT_DEN	Inactive nest density. Using only "Inactive" nests to create the nest density grid, density grid cell values were extracted to each nest.
ASPECT	Gird cell values for apsect at each nest.
SLP_PERC	Grid cell values for percent slope at each nest.
ELEV	Grid cell values for elevation at each nest.
NEAR_DIST_NEST	Distance between nests. This variable was created to examine patterns in clustering of nests. The values represent the nearest distance to another nest and units were recorded in meters.
NEAR_DPW	Distance to the nearest producing well. This variable was created to examine patterns proximity of nest to active (e.g., producing) natural gas wells. The values represent the distance (in meters) from the nest to the nearest surface hole location (represented as a point).
NEAR_DRD	Distance to the nearest road. This variable was created to examine patterns proximity of nest to roads. The values represent the straight-line distance (in meters) from the nest to the nearest linear feature (represented as a line).
NEAR_SURF_D	Distance to the nearest edge of disturbance. This variable was created to examine patterns proximity of nest to known anthropogenic disturbance featuers (e.g., natural gas well pad). The values represent the straight-line distance (in meters) from the nest to the nearest disturbance feature (represented as a polygon).

Table 5. The following table provides a summary of nest success and productivity information for selected raptor species in the project area. Data were collected during the 2010 breeding season in northwest Colorado (Picance Basin, Rio Blanco County).

Species	Failed	Successful	Unknown	Total Active Nests	% of Total	No. Fledged (NF)	Mean NF/Successful Nest
AMKE	NA	NA	2	2	1.23		
BAEA	NA	1	NA	1	0.62	1	1.00
COHA	8	49	5	62	38.27	147	3.00
CORA	1	2	7	10	6.17	7	3.50
GHOW	NA	1	2	3	1.85	1	1.00
GOEA	NA	1	NA	1	0.62	1	1.00
LEOW	6	43	10	59	36.42	126	2.93
NOGH	NA	3	NA	3	1.85	7	2.33
PRFA	NA	2	1	3	1.85	2	1.00
RTHA	NA	6	10	16	9.88	15	2.50
SSHA	NA	1	NA	1	0.62	3	3.00
SWOW	NA	NA	1	1	0.62		
Total	15	109	38	162		310	

Table 6. The following table includes Spearman correlation values (r_s) for the variable combinations when data for all nests were used for correlation analyses. Values highlighted in bold exhibited a modest correlation. The following codes apply: ASP (aspect), NDEN (nest density), RDD (road density), DRD (distance to roads), ELEV(elevation), SLP (slope), DBN (distance between nests), DPW (distance to a producing well), DED (distance to edge of disturbance) PWD (producing well density). Values ranging from 0.00 to 0.19 represent no correlation to very weak, 0.20 to 0.39 (weak correlation), 0.40 to 0.69 (modest correlation), 0.70 to 0.89 (strong correlation), and 0.90 to 1.00 (very strong correlation) (Fowler et al. 1998).

Variable	ASP	NDEN	RDD	DRD	ELEV	SLP	DBN	DPW	DED	PWD
ASP	1.0000									
NDEN	0.0858	1.0000								
RDD	0.0504	-0.0677	1.0000							
DRD	0.0330	-0.1448	0.1026	1.0000						
ELEV	0.1663	-0.0602	0.0354	-0.0641	1.0000					
SLP	-0.0030	-0.1174	0.0460	0.0678	-0.1307	1.0000				
DBN	-0.0381	**-0.7235**	0.0634	0.1452	-0.0207	0.1814	1.0000			
DPW	-0.0987	-0.3352	0.1101	0.0015	0.0288	0.1283	0.2761	1.0000		
DED	-0.0830	-0.2147	-0.0208	0.0683	-0.0028	0.2172	0.1972	**0.6094**	1.0000	
PWD	-0.1998	-0.1309	-0.0126	0.0234	0.0617	0.0668	0.1189	0.2429	0.2703	1.0000

Table 7. The following tables include Spearman correlation values (r_s) for the variable combinations when data for active (above) and inactive (below) were used for correlation analyses. Values highlighted in bold exhibited a modest to strong correlation. The following codes apply: ASP (aspect), NDEN (nest density), ADEN (active nest density), IDEN (inactive nest density), RDD (road density), ELEV(elevation), SLP (slope), DBN (distance between nests), DPW (distance to a producing well), DRD (distance to roads), DED (distance to edge of disturbance) PWD (producing well density). Values ranging from 0.00 to 0.19 represent no correlation to very weak, 0.20 to 0.39 (weak correlation), 0.40 to 0.69 (modest correlation), 0.70 to 0.89 (strong correlation), and 0.90 to 1.00 (very strong correlation) (Fowler et al. 1998).

Variable	ASP	SLP	ADEN	RDD	ELEV	DBN	DPW	DRD	DED	PWD
ASP	1.0000									
SLP	0.0118	1.0000								
ADEN	0.0958	-0.0446	1.0000							
RDD	0.0886	-0.0238	0.0094	1.0000						
ELEV	0.2187	-0.1032	-0.1697	0.0393	1.0000					
DBN	-0.0397	0.1179	**-0.5990**	0.0463	0.0845	1.0000				
DPW	-0.0452	0.1495	-0.2539	0.1675	-0.0795	0.2653	1.0000			
DRD	0.0201	0.0395	-0.1123	0.1919	-0.0582	0.1444	0.1090	1.0000		
DED	-0.0923	0.1566	-0.1879	0.0635	-0.0514	0.1276	**0.5792**	-0.0146	1.0000	
PWD	-0.0995	0.0178	0.0352	0.0486	0.0710	0.0897	0.1160	0.1243	0.2281	1.0000

Variable	IDEN	SLP	ASP	DRD	ELEV	RDD	DBN	DED	DPW	PWD
IDEN	1.0000									
SLP	-0.3934	1.0000								
ASP	-0.2378	-0.3978	1.0000							
DRD	0.1600	-0.3363	0.0022	1.0000						
ELEV	0.0689	0.1429	-0.1516	-0.2659	1.0000					
RDD	-0.0578	-0.0945	0.1780	0.0681	0.2615	1.0000				
DBN	0.0178	0.2137	-0.1322	-0.2401	0.1123	0.1718	1.0000			
DED	-0.2067	0.1165	-0.1868	-0.1341	0.0374	-0.1648	0.2291	1.0000		
DPW	0.0556	-0.1736	-0.0505	0.2264	-0.1604	0.0945	0.3282	**0.8286**	1.0000	
PWD	-0.3591	-0.0659	-0.0604	-0.0055	0.0110	0.4011	0.5372	**0.6758**	**0.7143**	1.0000

Table 8. The following tables include Spearman correlation values (r_s) for the variable combinations when data for COHA (above) and LEOW (below) were used for correlation analyses. Values highlighted in bold exhibited a modest to strong correlation. The following codes apply: ASP (aspect), NDEN (nest density), ADEN (active nest density), IDEN (inactive nest density), RDD (road density), ELEV(elevation), SLP (slope), DBN (distance between nests), DPW (distance to a producing well), DRD (distance to roads), DED (distance to edge of disturbance) PWD (producing well density). Values ranging from 0.00 to 0.19 represent no correlation to very weak, 0.20 to 0.39 (weak correlation), 0.40 to 0.69 (modest correlation), 0.70 to 0.89 (strong correlation), and 0.90 to 1.00 (very strong correlation) (Fowler et al. 1998).

Variable	RDD	NDEN	ASP	ADEN	DBN	ELEV	SLP	DRD	DED	DPW	PWD
RDD	1.0000										
NDEN	-0.2078	1.0000									
ASP	0.1652	-0.1722	1.0000								
ADEN	-0.1054	**0.8207**	-0.1861	1.0000							
DBN	0.1192	**-0.8128**	0.2721	**-0.7178**	1.0000						
ELEV	0.0455	-0.1160	0.3062	0.0461	0.1944	1.0000					
SLP	-0.1259	0.2794	-0.1269	**0.4583**	-0.3039	0.0162	1.0000				
DRD	0.1971	-0.3194	0.1562	-0.2140	0.2498	0.0922	-0.0087	1.0000			
DED	-0.1656	0.0787	-0.3543	0.0529	-0.1241	-0.1303	0.3689	-0.2332	1.0000		
DPW	-0.1264	-0.3097	-0.1623	-0.2564	0.2576	-0.1198	0.1524	0.1529	**0.4801**	1.0000	
PWD	-0.2179	-0.1294	-0.0856	-0.0371	-0.0188	0.0124	0.1059	0.2331	0.2443	0.3239	1.0000

Variable	SLP	ASP	DBN	ELEV	RDD	DRD	NDEN	DPW	DED	ADEN	PWD
SLP	1.0000										
ASP	0.0026	1.0000									
DBN	0.0109	0.0727	1.0000								
ELEV	-0.1394	0.3439	0.2219	1.0000							
RDD	-0.0288	0.1504	-0.1391	0.0311	1.0000						
DRD	0.1152	-0.0159	-0.0816	-0.0007	-0.1612	1.0000					
NDEN	0.0735	-0.2197	**-0.4096**	-0.3868	0.0883	-0.0476	1.0000				
DPW	-0.0955	-0.0662	0.0560	0.1125	0.1437	-0.0826	-0.2155	1.0000			
DED	-0.0577	-0.0402	-0.1179	0.1047	0.0296	-0.1632	-0.1404	**0.6274**	1.0000		
ADEN	0.0515	-0.0874	-0.1619	**-0.5201**	0.1124	-0.0403	**0.6806**	-0.3197	-0.1112	1.0000	
PWD	-0.3275	-0.3032	-0.1976	-0.1375	-0.1073	-0.0486	-0.0267	0.0416	0.2543	0.2595	1.0000

Table 9. The following table includes results for the one-way ANOVA. To complete this analysis, the response variable was compared to the categorical factor STATUS_10 which included 2 levels ("ACTIVE" and "INACTIVE"). We did not find a statistical difference between Active and Inactive nests when comparing response variable means. Though not statistically significant, active nests appeared to be closer to linear features when compared to inactive nests; this weak relationship was also confirmed with the non-parametric alternative (Kruskal-Wallis chi-squared = 2.9533, *df* = 1, *p* = 0.0857).

Variable	*n*	*F*	*p*
PWD	148	1.16	0.28
RDD	183	1.47	0.23
ELEV	183	1.74	0.19
ASPECT	183	1.91	0.17
SLP	183	0.15	0.7
NEST_DEN	183	0.34	0.56
NEAR_DIST_NEST	183	2.66	0.1
DPW	183	1.31	0.25
DRD	183	3.51	0.06
SURF_DIST	183	0.11	0.74

Table 10. The following table summarizes each response variable using untransformed data and was grouped by STATUS_10 (e.g., ACTIVE and INACTIVE). ANOVA tests showed that there were no statistically significant differences between active and inactive nests when comparing response variable means. However, active nests were generally located closer to roads ($\bar{x}$ = 225.47 m) compared to inactive nests ($\bar{x}$ = 302.96 m). Distance measurements are reported in meters and elevation is reported in feet. Density estimates are reported in number of units (e.g., nests, producing wells, miles of linear features, etc.) per square mile. Aspect is reported in degrees, and slope is reported in units of percent slope.

Variable:	**NF_10**			
	mean	sd	n	NA
ACTIVE	2.87	1.10	108	54
INACTIVE	NaN	NA	0	21

Variable:	**PWD_SQMI**			
	mean	sd	n	NA
ACTIVE	2.73	3.98	128	34
INACTIVE	1.72	1.69	20	1

Variable:	**RDD**			
	mean	sd	n	NA
ACTIVE	2.32	0.93	162	0
INACTIVE	2.08	1.00	21	0

Variable:	**NEST_DEN**			
	mean	sd	n	NA
ACTIVE	2.89	1.45	162	0
INACTIVE	2.60	0.85	21	0

Variable:	**ACT_DEN**			
	mean	sd	n	NA
ACTIVE	2.10	0.97	162	0
INACTIVE	NaN	NA	0	21

Variable:	**INACT_DEN**			
	mean	sd	n	NA
ACTIVE	NaN	NA	0	162
INACTIVE	1.81	0.79	21	0

Variable:	**ASPECT**			
	mean	sd	n	NA
ACTIVE	174.83	115.44	162	0
INACTIVE	199.19	99.77	21	0

Variable:	**SLP_PERC**			
	mean	sd	n	NA
ACTIVE	21.80	16.45	162	0
INACTIVE	28.57	26.67	21	0

Variable:	**ELEV**			
	mean	sd	n	NA
ACTIVE	6741.92	319.86	162	0
INACTIVE	6856.95	517.53	21	0

Variable:	**NEAR_DIST_NEST**			
	mean	sd	n	NA
ACTIVE	814.27	2214.45	162	0
INACTIVE	414.15	419.18	21	0

Variable:	**NEAR_DPW**			
	mean	sd	n	NA
ACTIVE	1251.54	1179.52	162	0
INACTIVE	853.66	387.08	21	0

Variable:	**NEAR_DRD**			
	mean	sd	n	NA
ACTIVE	225.47	181.73	162	0
INACTIVE	302.96	231.00	21	0

Variable:	**NEAR_SURF_D**			
	mean	sd	n	NA
ACTIVE	618.97	517.00	162	0
INACTIVE	597.10	509.40	21	0

Table 11. The following table includes results for the one-way, single factor ANOVA. To complete this analysis, the response variable was compared to the categorical factor END_10 which included 2 levels ("SUCCESSFUL" and "FAILED"). ANOVA tests showed that there were no statistically significant differences between successful and failed nests when comparing response variable means. Though not statistically significant, we did note a weak relationship when comparing producing well density (PWD) to nests that were successful versus nests that failed. Successful nests were located in areas where producing well density was, on average, higher, and failed nests were located in areas where producing well density was, on average, lower. The strength of this relationship was also confirmed with the non-parametric alternative (Kruskal-Wallis chi-squared = 2.76, *df* = 1, *p* = 0.0964).

Variable	*F*	*p*
PWD	3.67	0.06
RDD	0.03	0.86
ELEV	1.06	0.31
ASPECT	0.33	0.57
SLP	0.01	0.90
NEST_DEN	0.53	0.47
NEAR_DIST_NEST	0.18	0.67
DPW	0.04	0.84
DRD	0.02	0.90
SURF_DIST	0.08	0.78

Table 12. The following table summarizes each response variable using untransformed data and was grouped by END_10 (e.g., SUCCESSFUL and FAILED). ANOVA tests showed that there were no statistically significant differences between successful and failed nests when comparing response variable means. However, as mentioned in Table 11, we did note that successful nests were generally located in areas with more producing wells ($\bar{x}$ = 2.97 wells/mi^2) compared to failed nests ($\bar{x}$ = 1.07 wells/mi^2) where producing well density was lower. Distance measurements are reported in meters and elevation is reported in feet. Density estimates are reported in number of units (e.g., nests, producing wells, miles of linear features, etc.) per square mile. Aspect is reported in degrees, and slope is reported in units of percent slope.

Variable:	**PWD_SQMI**				Variable:	**RDD**				Variable:	**NEST_DEN**			
	mean	sd	n	NA		mean	sd	n	NA		mean	sd	n	NA
FAILED	1.07	1.12	15	0	FAILED	2.31	1.40	15	0	FAILED	3.35	1.43	15	0
SUCCESSFUL	2.97	4.13	83	26	SUCCESSFUL	2.29	0.89	109	0	SUCCESSFUL	3.07	1.47	109	0

Variable:	**ACT_DEN**				Variable:	**ASPECT**				Variable:	**SLP_PERC**			
	mean	sd	n	NA		mean	sd	n	NA		mean	sd	n	NA
FAILED	2.29	0.91	15	0	FAILED	192.84	137.20	15	0	FAILED	17.55	7.97	15	0
SUCCESSFUL	2.19	1.00	109	0	SUCCESSFUL	177.11	114.64	109	0	SUCCESSFUL	18.95	12.92	109	0

Variable:	**ELEV**				Variable:	**NEAR_DIST_NEST**				Variable:	**NEAR_DPW**			
	mean	sd	n	NA		mean	sd	n	NA		mean	sd	n	NA
FAILED	6794.39	231.54	15	0	FAILED	390.97	435.73	15	0	FAILED	1078.77	635.06	15	0
SUCCESSFUL	6726.45	244.28	109	0	SUCCESSFUL	613.25	1319.59	109	0	SUCCESSFUL	1138.26	1189.44	109	0

Variable:	**NEAR_DRD**				Variable:	**NEAR_SURF_D**			
	mean	sd	n	NA		mean	sd	n	NA
FAILED	207.04	130.51	15	0	FAILED	563.95	363.96	15	0
SUCCESSFUL	219.31	181.88	109	0	SUCCESSFUL	545.19	411.12	109	0

Table 13. The following table includes results for the one-way, single factor ANOVA. To complete this analysis, the response variables were compared with the categorical factor SPP_10 which included 2 factors ("COHA" and "LEOW"). We noted a statistically significant difference among COHA and LEOW (highlighted with "**") when comparing the response variable NEST_DEN (i.e., nest density) and DIST_M (i.e., distance between nests) at occupied nests. LEOW nests appeared to be distributed closer together (i.e., exhibited higher density) when compared to COHA nests, which tended to be less clustered.

Variable	*n*	*F*	*p*	
PWD	96	0.07	0.79	
RDD				
ELEV	121	0.42	0.52	
ASPECT	121	0.32	0.57	
SLP	121	0.07	0.79	
NEST_DEN	121	8.22	0.005	**
ACT_DEN	121	3.5	0.063	
DIST_M	121	9.99	0.0019	**
DPW	121	1.09	0.30	
DRD	121	0.17	0.68	
SURF_DIST	121	0.18	0.68	

Table 14. The following table summarizes each response (raw data) variable and was grouped by species. Distance measurements are reported in meters and elevation is reported in feet. Density estimates are reported in number of units (e.g., nests, producing wells, miles of linear features, etc.) per square mile. Aspect is reported in degrees, and slope is reported in units of percent slope. Data were collected during the 2010 breeding season in northwest Colorado (Picance Basin, Rio Blanco County).

Variable:	**NF_10**				Variable:	**PWD_SQMI**				Variable:	**RDD**			
	mean	sd	n	NA		mean	sd	n	NA		mean	sd	n	NA
AMKE	NaN	NA	0	2	AMKE	0.42	NA	1	1	AMKE	3.31	0.15	2	0
BAEA	1.00	NA	1	0	BAEA	NaN	NA	0	1	BAEA	2.16	NA	1	0
COHA	3.00	0.96	49	13	COHA	2.61	4.06	47	15	COHA	2.30	0.97	62	0
CORA	3.50	0.71	2	8	CORA	0.81	0.79	9	1	CORA	2.20	0.75	10	0
GHOW	1.00	NA	1	2	GHOW	3.23	4.30	3	0	GHOW	2.44	0.73	3	0
GOEA	1.00	NA	1	0	GOEA	3.13	NA	1	0	GOEA	0.94	NA	1	0
LEOW	3.00	1.21	42	17	LEOW	2.55	3.77	49	10	LEOW	2.36	0.98	59	0
NOGH	2.33	0.58	3	0	NOGH	4.25	4.89	3	0	NOGH	2.80	0.48	3	0
PRFA	1.00	0.00	2	1	PRFA	5.66	4.41	2	1	PRFA	1.96	0.80	3	0
RTHA	2.50	0.84	6	10	RTHA	4.12	5.30	11	5	RTHA	2.37	0.85	16	0
SSHA	3.00	NA	1	0	SSHA	12.03	NA	1	0	SSHA	1.47	NA	1	0
SWOW	NaN	NA	0	1	SWOW	0.39	NA	1	0	SWOW	1.96	NA	1	0
UNK	NaN	NA	0	122	UNK	2.18	2.96	89	33	UNK	2.22	0.81	122	0

Variable:	**NEST_DEN**				Variable:	**ACT_DEN**				Variable:	**ASPECT**			
	mean	sd	n	NA		mean	sd	n	NA		mean	sd	n	NA
AMKE	1.25	0.41	2	0	AMKE	1.25	0.41	2	0	AMKE	149.28	76.87	2	0
BAEA	1.64	NA	1	0	BAEA	1.64	NA	1	0	BAEA	321.77	NA	1	0
COHA	2.69	1.26	62	0	COHA	2.00	0.91	62	0	COHA	168.69	122.11	62	0
CORA	2.91	1.41	10	0	CORA	2.31	1.28	10	0	CORA	189.36	123.47	10	0
GHOW	1.12	0.14	3	0	GHOW	1.08	0.13	3	0	GHOW	135.04	62.59	3	0
GOEA	0.95	NA	1	0	GOEA	0.95	NA	1	0	GOEA	159.32	NA	1	0
LEOW	3.46	1.57	59	0	LEOW	2.34	1.02	59	0	LEOW	179.60	122.18	59	0
NOGH	3.69	0.60	3	0	NOGH	2.48	0.17	3	0	NOGH	263.24	80.81	3	0
PRFA	1.15	0.22	3	0	PRFA	1.15	0.22	3	0	PRFA	178.05	68.77	3	0
RTHA	2.30	1.00	16	0	RTHA	1.76	0.67	16	0	RTHA	154.75	82.72	16	0
SSHA	3.09	NA	1	0	SSHA	3.09	NA	1	0	SSHA	73.23	NA	1	0
SWOW	5.19	NA	1	0	SWOW	3.74	NA	1	0	SWOW	315.89	NA	1	0
UNK	2.97	1.46	122	0	UNK	NaN	NA	0	122	UNK	184.44	111.89	122	0

Table 14. Continued.

Variable: SLP_PERC	mean	sd	n	NA
AMKE	31.90	22.64	2	0
BAEA	28.47	NA	1	0
COHA	16.21	9.02	62	0
CORA	23.37	18.59	10	0
GHOW	36.50	17.06	3	0
GOEA	6.46	NA	1	0
LEOW	16.82	9.68	59	0
NOGH	21.72	6.42	3	0
PRFA	61.42	30.68	3	0
RTHA	48.27	20.31	16	0
SSHA	36.75	NA	1	0
SWOW	33.53	NA	1	0
UNK	22.40	19.06	122	0

Variable: ELEV	mean	sd	n	NA
AMKE	6702.66	453.55	2	0
BAEA	6513.12	NA	1	0
COHA	6741.99	282.59	62	0
CORA	6627.76	227.09	10	0
GHOW	6404.74	141.28	3	0
GOEA	6615.03	NA	1	0
LEOW	6772.97	256.46	59	0
NOGH	6647.69	248.95	3	0
PRFA	7061.05	363.79	3	0
RTHA	6780.65	609.77	16	0
SSHA	6528.56	NA	1	0
SWOW	6412.28	NA	1	0
UNK	6734.32	309.64	122	0

Variable: NEAR_DIST_NEST	mean	sd	n	NA
AMKE	1476.70	600.56	2	0
BAEA	643.47	NA	1	0
COHA	1128.92	3431.05	62	0
CORA	730.32	1196.82	10	0
GHOW	1660.10	716.38	3	0
GOEA	1643.90	NA	1	0
LEOW	362.63	539.50	59	0
NOGH	301.08	182.58	3	0
PRFA	1667.41	1009.93	3	0
RTHA	1018.26	899.82	16	0
SSHA	531.43	NA	1	0
SWOW	270.71	NA	1	0
UNK	641.95	1482.18	122	0

Variable: NEAR_DPW	mean	sd	n	NA
AMKE	2562.79	821.27	2	0
BAEA	2554.99	NA	1	0
COHA	1236.89	1411.41	62	0
CORA	1194.04	895.18	10	0
GHOW	1803.22	2204.77	3	0
GOEA	2790.71	NA	1	0
LEOW	985.57	778.26	59	0
NOGH	1799.02	1495.23	3	0
PRFA	2331.16	1063.76	3	0
RTHA	1484.45	1265.68	16	0
SSHA	1872.85	NA	1	0
SWOW	2078.15	NA	1	0
UNK	1133.91	967.07	122	0

Variable: NEAR_DRD	mean	sd	n	NA
AMKE	391.20	18.55	2	0
BAEA	190.66	NA	1	0
COHA	216.87	173.73	62	0
CORA	249.99	240.96	10	0
GHOW	261.09	282.23	3	0
GOEA	49.78	NA	1	0
LEOW	233.71	202.56	59	0
NOGH	258.93	97.67	3	0
PRFA	240.89	159.54	3	0
RTHA	210.76	107.00	16	0
SSHA	93.29	NA	1	0
SWOW	20.13	NA	1	0
UNK	234.20	193.53	122	0

Variable: NEAR_SURF_D	mean	sd	n	NA
AMKE	1325.47	857.42	2	0
BAEA	1222.99	NA	1	0
COHA	565.79	473.62	62	0
CORA	768.26	478.83	10	0
GHOW	863.24	776.22	3	0
GOEA	786.43	NA	1	0
LEOW	519.32	409.74	59	0
NOGH	724.35	655.38	3	0
PRFA	1342.40	877.37	3	0
RTHA	734.38	748.84	16	0
SSHA	1244.31	NA	1	0
SWOW	427.28	NA	1	0
UNK	567.51	690.06	122	0

Table 15. The following table includes distance categories for active nests and number of fledglings produced when using data for all successful nests. Distance measures were measured from each nest to the nearest producing well (DPW) and units are reported in meters. Data were collected during the 2010 breeding season in northwest Colorado (Picance Basin, Rio Blanco County).

Distance Category	*n*	No. Fledged (NF)	Mean NF/Nest	*SD*	*SE*
0 TO 100	1	4	4.00		
100 TO 200	5	15	3.00	0.71	
200 TO 300	5	13	2.60	1.52	
300 TO 400	7	23	3.29	0.76	
400 TO 500	12	35	2.92	1.00	
500 TO 600	8	28	3.50	1.07	
600 TO 700	7	16	2.29	1.38	
700 TO 800	5	12	2.40	1.14	
800 TO 900	8	18	2.25	1.16	
900 TO 1000	9	32	3.56	0.73	
1000 TO 1100	5	16	3.20	1.48	
1100 TO 1200	3	7	2.33	1.15	
1200 TO 1300	3	6	2.00	1.00	
1300 TO 1400	3	9	3.00	1.00	
1400 TO 1500	1	4	4.00		
1500 TO 1600	2	6	3.00	1.41	
1600 TO 1700	2	6	3.00	0.00	
1700 TO 1800	3	10	3.33	0.58	
1800 TO 1900	3	9	3.00	0.00	
1900 TO 2000	1	2	2.00		
2100 TO 2200	1	4	4.00		
2300 TO 2400	3	9	3.00	2.00	
2400 TO 2500	2	5	2.50	0.71	
2500 TO 2600	3	5	1.67	1.15	
2600 TO 2700	1	3	3.00		
2700 TO 2800	1	1	1.00		
3400 TO 3500	1	2	2.00		
3500 TO 3600	1	2	2.00		
3600 TO 3700	1	4	4.00		
10300 TO 10400	1	4	4.00		
Total	108	310	2.86		

Table 16. The following table includes distance categories for active nests and number of fledglings produced when using data for all successful nests. Distance measures were measured from each nest to the nearest road (DRD) and units are reported in meters. Data were collected during the 2010 breeding season in northwest Colorado (Picance Basin, Rio Blanco County).

Distance Category	*n*	No. Fledged (NF)	Mean NF/Nest	SD	SE
0 TO 100	29	82	2.83	1.17	
100 TO 200	31	95	3.06	1.15	
200 TO 300	20	55	2.75	0.97	
300 TO 400	13	31	2.38	0.96	
400 TO 500	9	27	3.00	1.12	
500 TO 600	2	8	4.00	0.00	
600 TO 700	2	8	4.00	0.00	
800 TO 900	1	1	1.00		
1100 TO 1200	1	3	3.00		
Total	108	310	2.89		

Table 17. The following table includes distance categories for active nests and number of fledglings produced when using data for all successful nests. Distance measures were measured from each nest to the nearest edge of disturbance (DED) and units are reported in meters. Data were collected during the 2010 breeding season in northwest Colorado (Picance Basin, Rio Blanco County).

Distance Category	*n*	No. Fledged (NF)	Mean NF/Nest	*SD*	*SE*
0 TO 100	10	30	3.00	1.05	
100 TO 200	12	35	2.92	1.31	
200 TO 300	13	45	3.46	0.88	
300 TO 400	17	46	2.71	0.99	
400 TO 500	10	29	2.90	1.37	
500 TO 600	8	23	2.88	1.46	
600 TO 700	6	15	2.50	1.05	
700 TO 800	7	17	2.43	0.98	
800 TO 900	6	14	2.33	1.21	
900 TO 1000	3	8	2.67	0.58	
1000 TO 1100	3	10	3.33	0.58	
1100 TO 1200	2	7	3.50	2.12	
1200 TO 1300	4	10	2.50	1.29	
1300 TO 1400	1	3	3.00		
1400 TO 1500	3	8	2.67	0.58	
1600 TO 1700	1	2	2.00		
1700 TO 1800	1	4	4.00		
1800 TO 1900	1	4	4.00		
Total	108	310	209.00		

Table 18. The following table includes distance categories for active nests and number of fledglings produced when using data for occupied LEOW and COHA nests. Distance measures were measured from each nest to the nearest road (DPW) and units are reported in meters. Data were collected during the 2010 breeding season in northwest Colorado (Picance Basin, Rio Blanco County).

	Cooper's Hawk					Long-eared Owl				
Distance Category	n_{COHA}	No. Fledged (NF)	Mean NF/Nest	*SD*	*SE*	n_{LEOW}	No. Fledged (NF)	Mean NF/Nest	*SD*	*SE*
0 TO 100	1	4	4.00							
100 TO 200	1	3	3.00			4	12	3.00	0.82	
200 TO 300	4	11	2.75	1.71		1	2	2.00		
300 TO 400	4	13	3.25	0.96		2	7	3.50	0.71	
400 TO 500	7	23	3.29	0.76		4	11	2.75	0.96	
500 TO 600	5	16	3.20	0.45		3	12	4.00	1.73	
600 TO 700						6	14	2.33	1.51	
700 TO 800	2	5	2.50	0.71		1	4	4.00		
800 TO 900	4	10	2.50	1.00		4	8	2.00	1.41	
900 TO 1000	3	9	3.00	0.00		5	20	4.00	0.71	
1000 TO 1100	2	9	4.50	0.71		3	7	2.33	1.15	
1100 TO 1200						1	3	3.00		
1200 TO 1300	2	4	2.00	1.41		1	2	2.00		
1300 TO 1400	2	6	3.00	1.41		1	3	3.00		
1400 TO 1500						1	4	4.00		
1500 TO 1600	1	2	2.00							
1600 TO 1700	1	3	3.00			1	3	3.00		
1700 TO 1800	2	7	3.50	0.71						
1800 TO 1900	1	3	3.00			1	3	3.00		
1900 TO 2000	1	2	2.00							
2000 TO 2100										
2100 TO 2200	1	4	4.00							
2300 TO 2400	1	1	1.00			1	5	5.00		
2400 TO 2500	1	2	2.00							
2500 TO 2600	1	3	3.00							
2600 TO 2700	1	3	3.00							
3200 TO 3300										
3400 TO 3500						1	2	2.00		
3600 TO 3700						1	4	4.00		
10300 TO 10400	1	4	4.00							
Total	49	147	2.93			42	126	3.10		

Table 19. The following table includes distance categories for active nests and number of fledglings produced when using data for occupied LEOW and COHA nests. Distance measures were measured from each nest to the nearest road (DRD) and units are reported in meters. Data were collected during the 2010 breeding season in northwest Colorado (Picance Basin, Rio Blanco County).

	Cooper's Hawk					Long-eared Owl				
Distance Category	n_{COHA}	No. Fledged (NF)	Mean NF/Nest	*SD*	*SE*	n_{LEOW}	No. Fledged (NF)	Mean NF/Nest	*SD*	*SE*
0 TO 100	13	44	3.38	0.87		12	29	2.42	1.16	
100 TO 200	15	46	3.07	0.80		12	42	3.50	1.31	
200 TO 300	7	18	2.57	0.98		8	23	2.88	1.25	
300 TO 400	6	15	2.50	0.84		4	12	3.00	0.82	
400 TO 500	4	11	2.75	1.26		4	13	3.25	1.26	
500 TO 600	2	8	4.00	0.00						
600 TO 700	1	4	4.00			1	4	4.00		
700 TO 800										
800 TO 900	1	1	1.00							
1100 TO 1200						1	3	3.00		
Total	49	147	2.91			42	126	3.15		

Table 20. The following table includes distance categories for active nests and number of fledglings produced when using data for occupied LEOW and COHA nests. Distance measures were measured from each nest to the nearest edge of disturbance (DED) and units are reported in meters. Data were collected during the 2010 breeding season in northwest Colorado (Picance Basin, Rio Blanco County).

	Long-eared Owl					Cooper's Hawk				
Distance Category	n_{LEOW}	No. Fledged (NF)	Mean NF/Nest	*SD*	*SE*	n_{COHA}	No. Fledged (NF)	Mean NF/Nest	*SD*	*SE*
0 TO 100	5	16	3.20	0.84		5	14	2.80	1.30	
100 TO 200	5	16	3.20	1.30		5	13	2.60	1.67	
200 TO 300	4	13	3.25	0.96		7	26	3.71	0.95	
300 TO 400	3	9	3.00	1.00		12	34	2.83	0.94	
400 TO 500	5	14	2.80	2.05		5	15	3.00	0.00	
500 TO 600	6	19	3.17	1.47		1	3	3.00		
600 TO 700	2	3	1.50	0.71		3	10	3.33	0.58	
700 TO 800	3	7	2.33	1.15		2	6	3.00	0.00	
800 TO 900	1	4	4.00			3	8	2.67	0.58	
900 TO 1000	1	3	3.00			1	2	2.00		
1000 TO 1100	1	3	3.00			2	7	3.50	0.71	
1100 TO 1200	2	7	3.50	2.12						
1200 TO 1300						1	2	2.00		
1300 TO 1400	1	3	3.00							
1400 TO 1500	1	3	3.00			1	3	3.00		
1600 TO 1700	1	2	2.00							
1700 TO 1800						1	4	4.00		
1800 TO 1900	1	4	4.00							
Total	42	126	3.00			49	147	2.96		

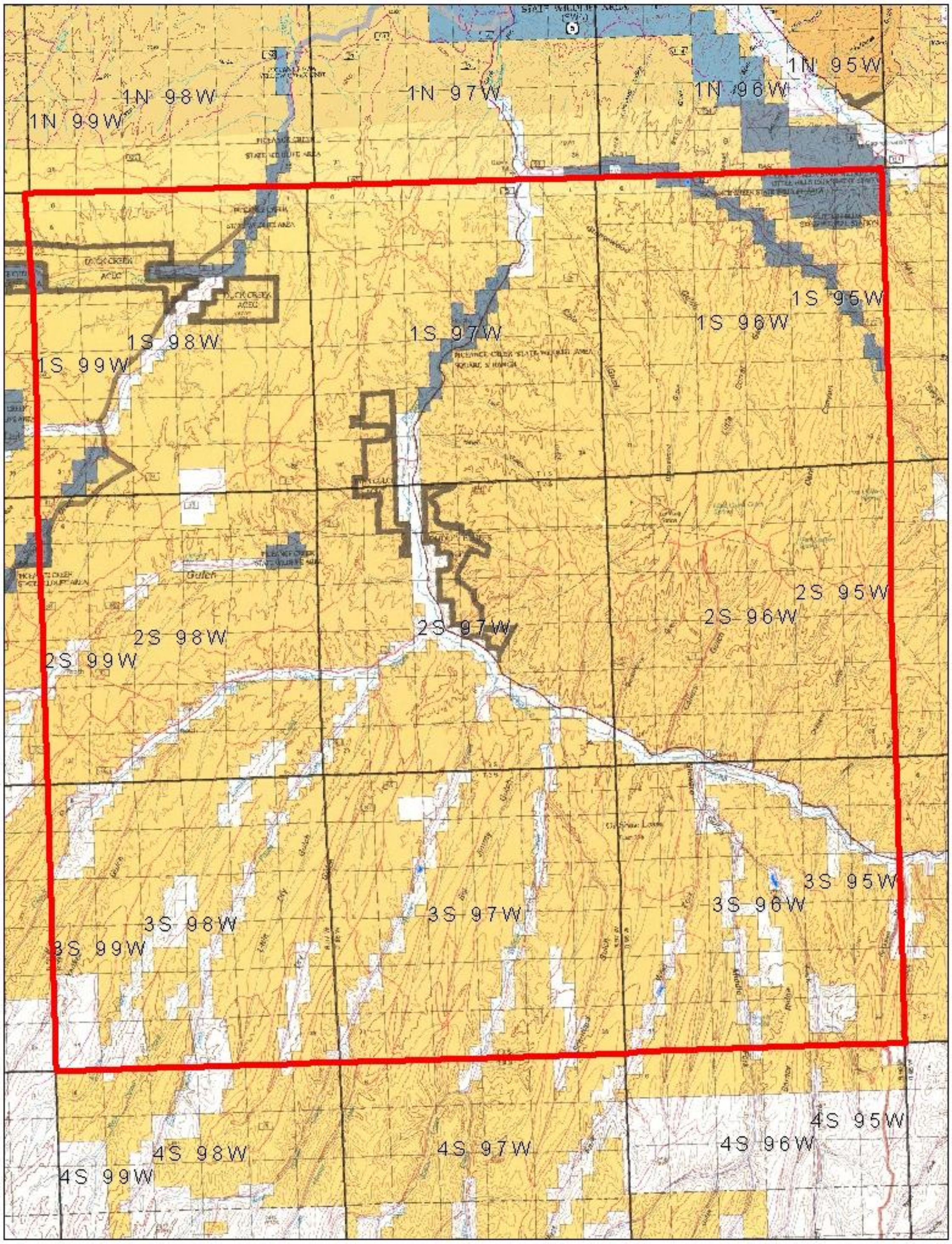
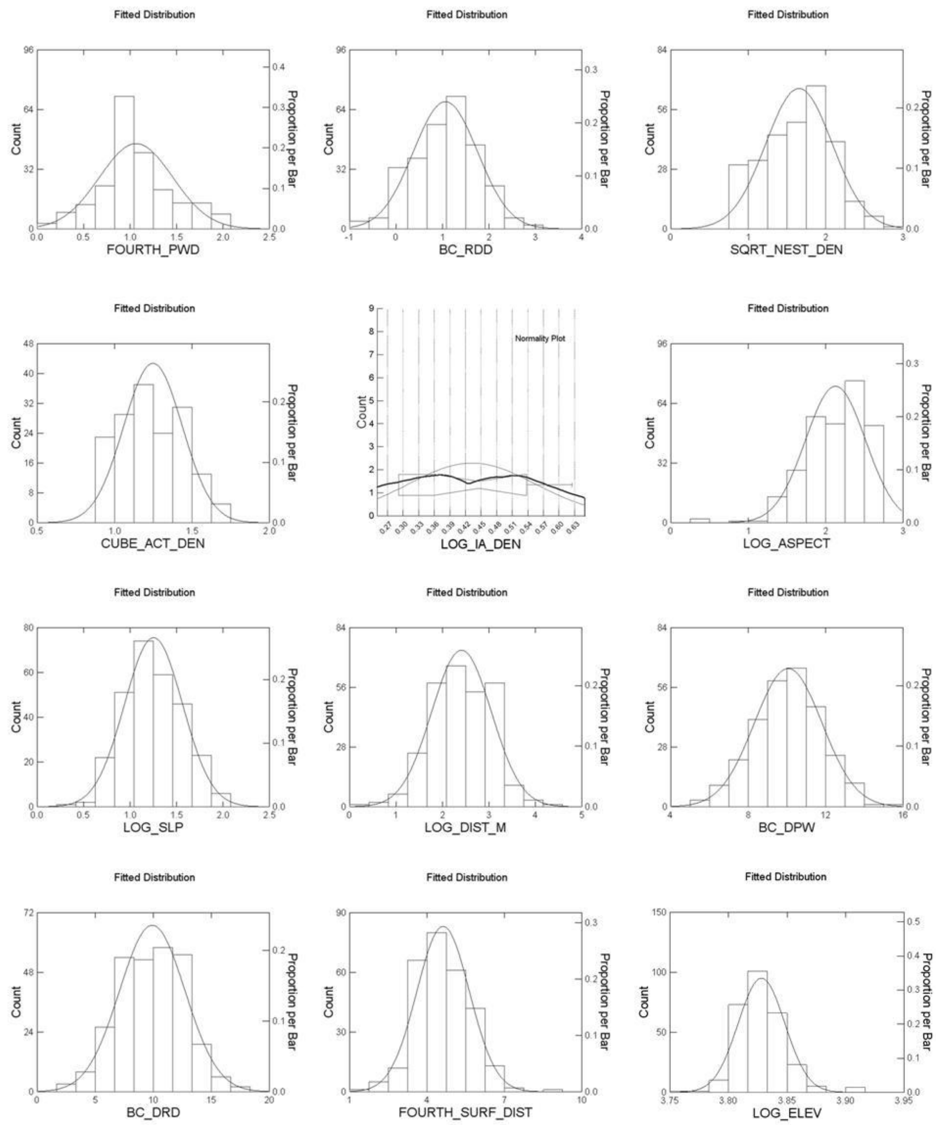


Figure 1. This figure depicts the study area (in red) where raptor breeding season information was collected during the 2010 breeding season in Piceance Basin, Rio Blanco County, Colorado.

Figure 2. The image above shows a typical Cooper's hawk nest tree, nest structure, and nest stand. These photos were taken while visiting the known nest tree(s) to assess the breeding season status of the nest area.



The following lambda (λ) values were used for Box-Cox transformations:

RDD: $\lambda = 0.687$ (95%CI = 0.4256 to 1.0148, $L = 38.65$)
DPW: $\lambda = 0.109$ (95% CI = -.00007 to 0.22784, $L = -1863.49$)
DRD: $\lambda = 0.229$ (95% CI = 0.1922 to 0.5424, $L = -1404.19$)

The following transformation codes apply:

FOURTH: Fourth root
CUBE: Cube root
SQRT: Square root
LOG: Log_{10} transformation
BC: Box-Cox transformation

Figure 3. The figure above shows the frequency distribution of the transformed data for each response variable.

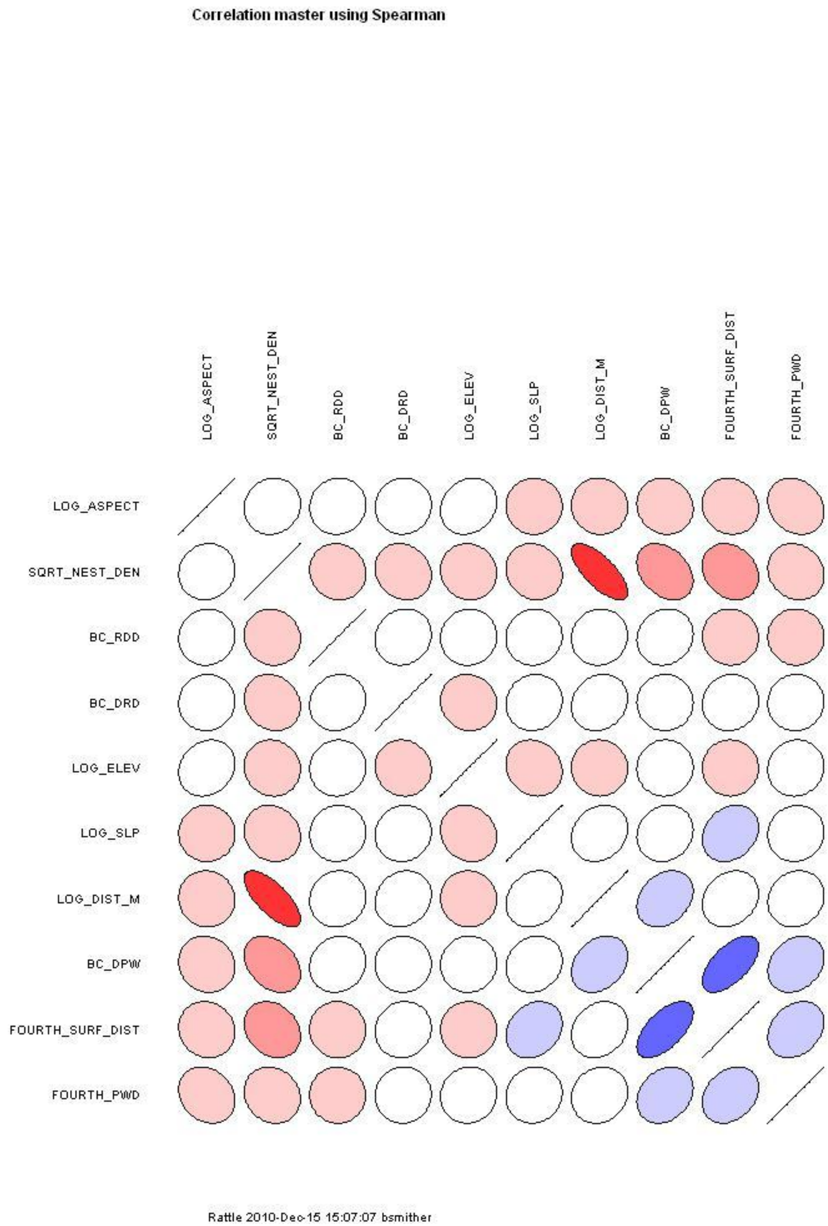


Figure 4. The above figure illustrates the degree of correlation between the response variables when *all nests* were used. The data used in this analysis were transformed. Moreover, because the data did not follow a normal frequency distribution, the Spearman correlation method was used. Darker colors represent a stronger correlation. The stronger the correlation, the more elliptical the shape for each variable combination.

Figure 5. The above figure illustrates the degree of correlation between the response variables when *active* (left) and *inactive* nests (right) were used for correlation analyses. The data used in this analysis were transformed. Moreover, because the data did not follow a normal frequency distribution, the Spearman correlation method was used. Darker colors represent a stronger correlation. The stronger the correlation, the more elliptical the shape for each variable combination.

Figure 6. The above figure illustrates the degree of correlation between the response variables when *Cooper's hawk* (left) and *Long-eared owl* nests (right) were used for correlation analyses. The data used in this analysis were transformed. Moreover, because the data did not follow a normal frequency distribution, the Spearman correlation method was used. Darker colors represent a stronger correlation. The stronger the correlation, the more elliptical the shape for each variable combination.

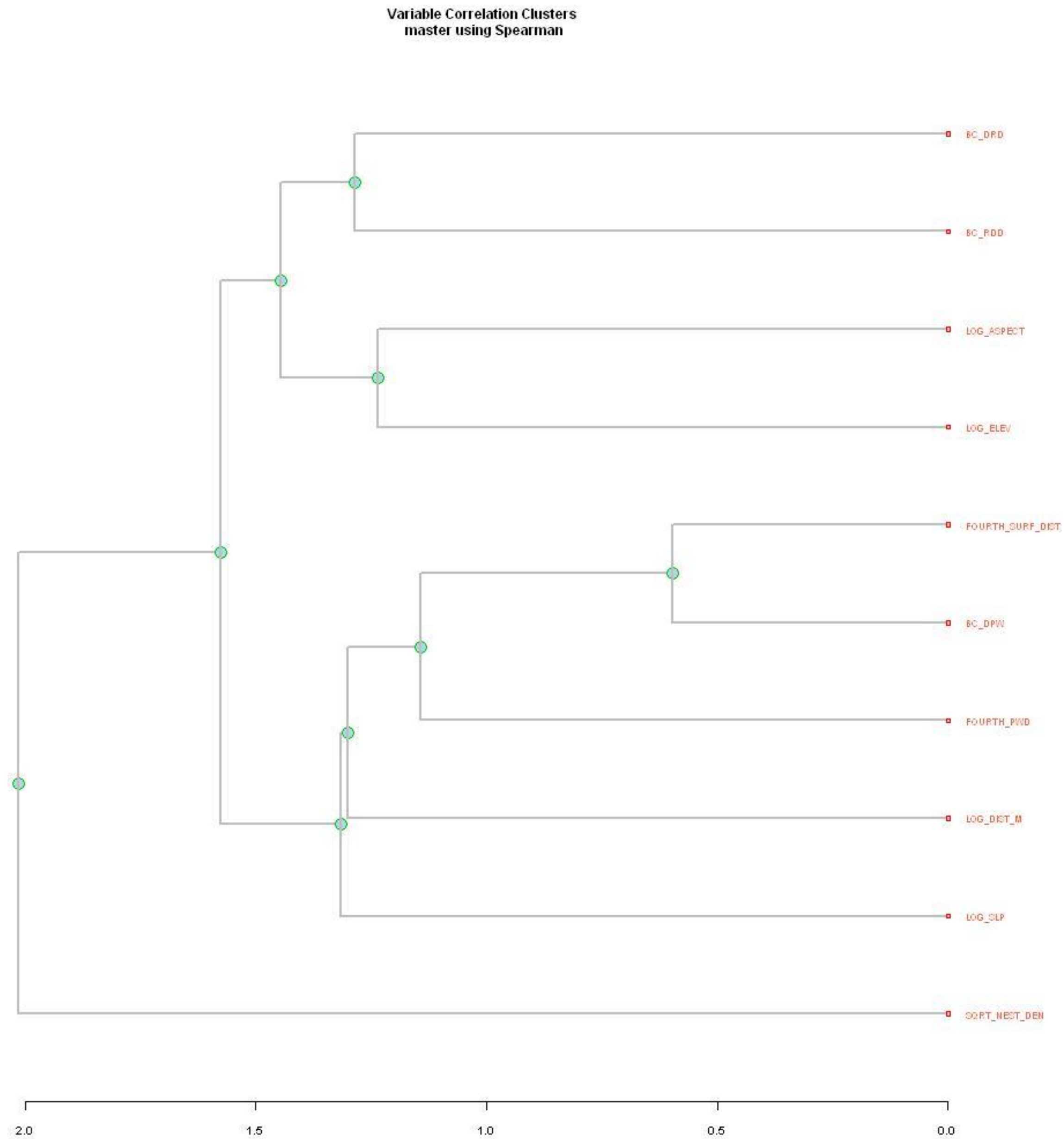


Figure 7. The above figure illustrates the degree of correlation between the response variables when *all nests* were used. The data used in this analysis were transformed. Moreover, because the data did not follow a normal frequency distribution, the Spearman correlation method was used.

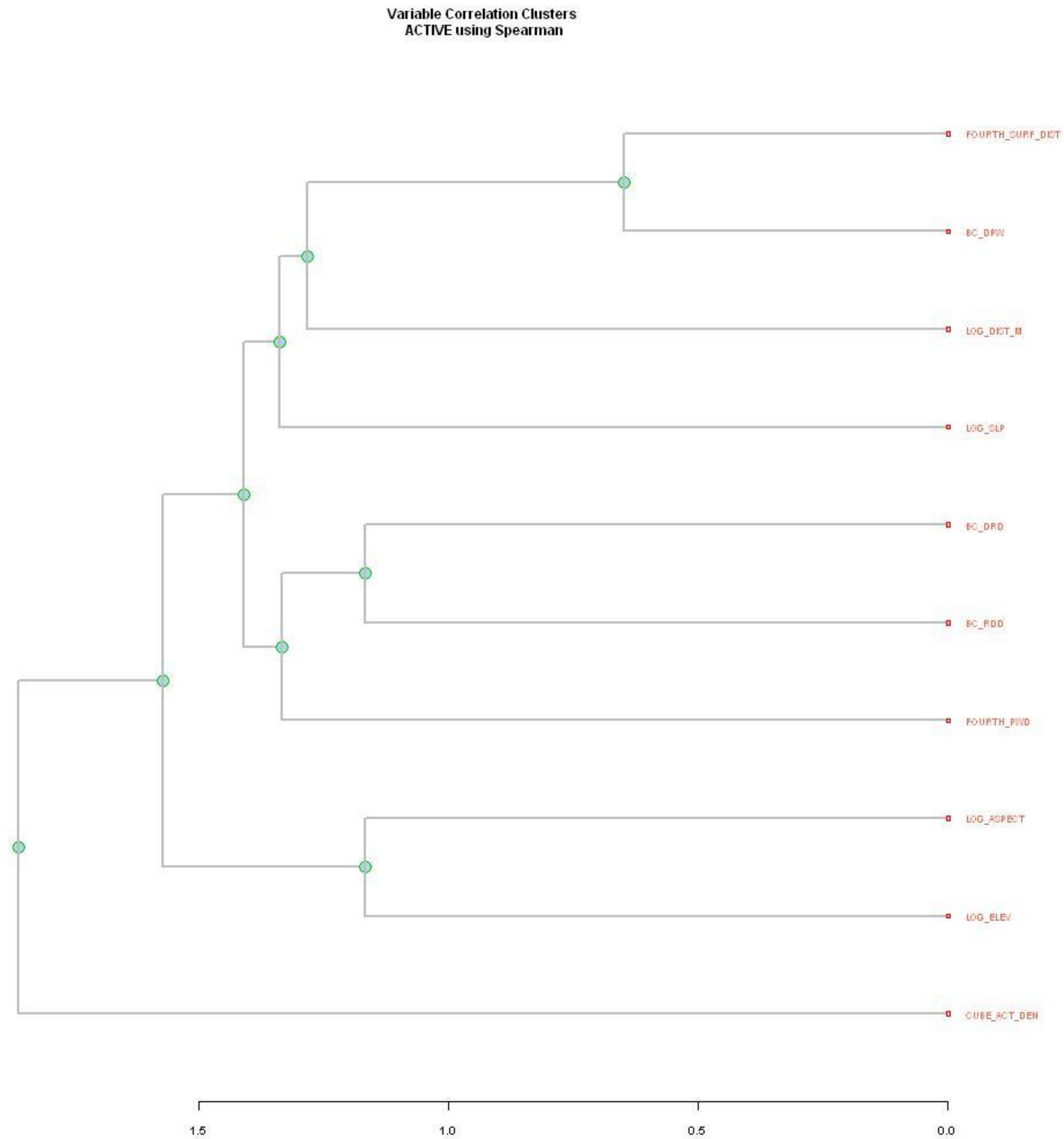


Figure 8. The above figure illustrates the degree of correlation between the response variables when only *active nests* were used. The data used in this analysis were transformed. Moreover, because the data did not follow a normal frequency distribution, the Spearman correlation method was used.

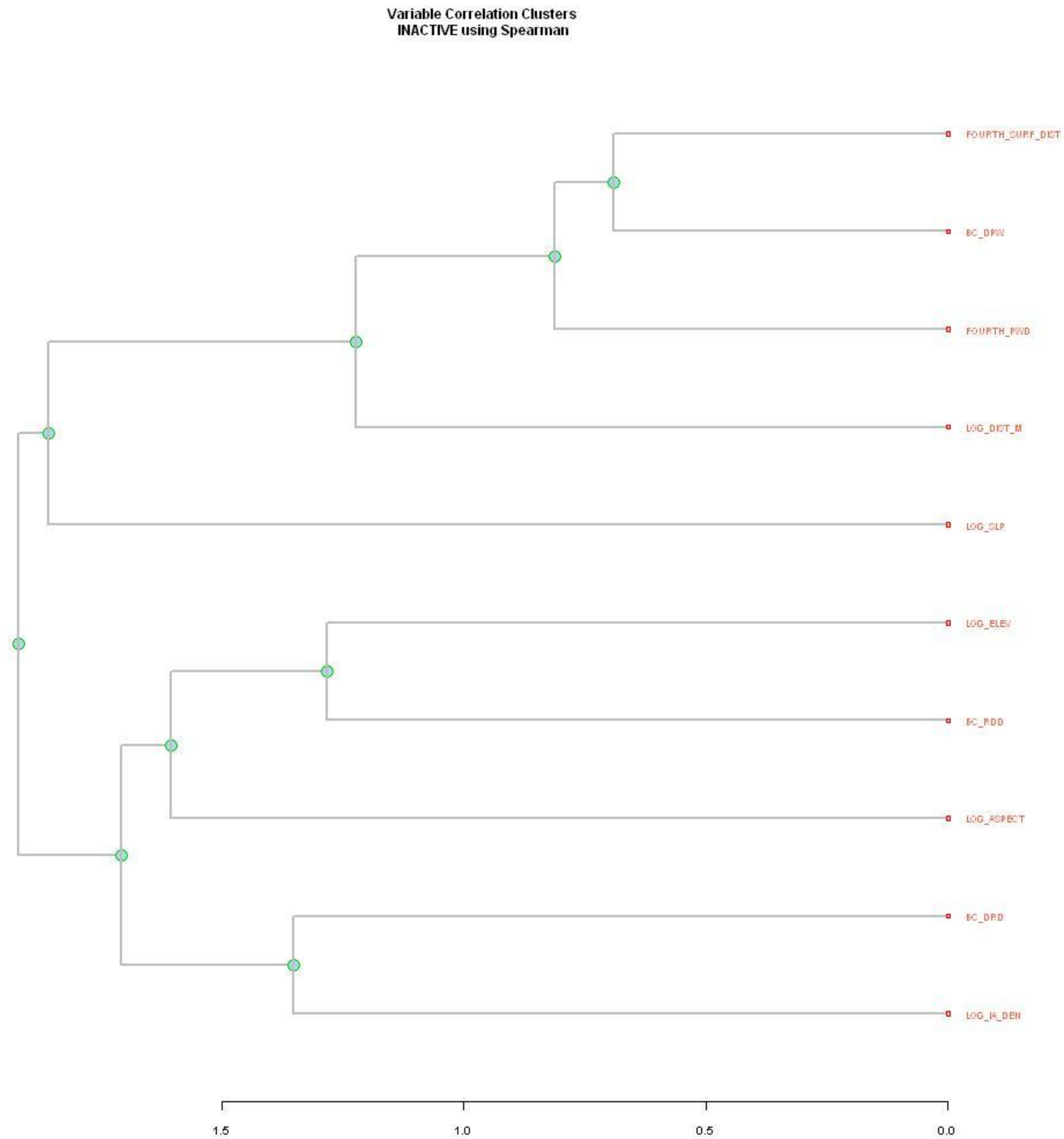


Figure 9. The above figure illustrates the degree of correlation between the response variables when only *inactive nests* were used. The data used in this analysis were transformed. Moreover, because the data did not follow a normal frequency distribution, the Spearman correlation method was used. Darker colors represent a stronger correlation.

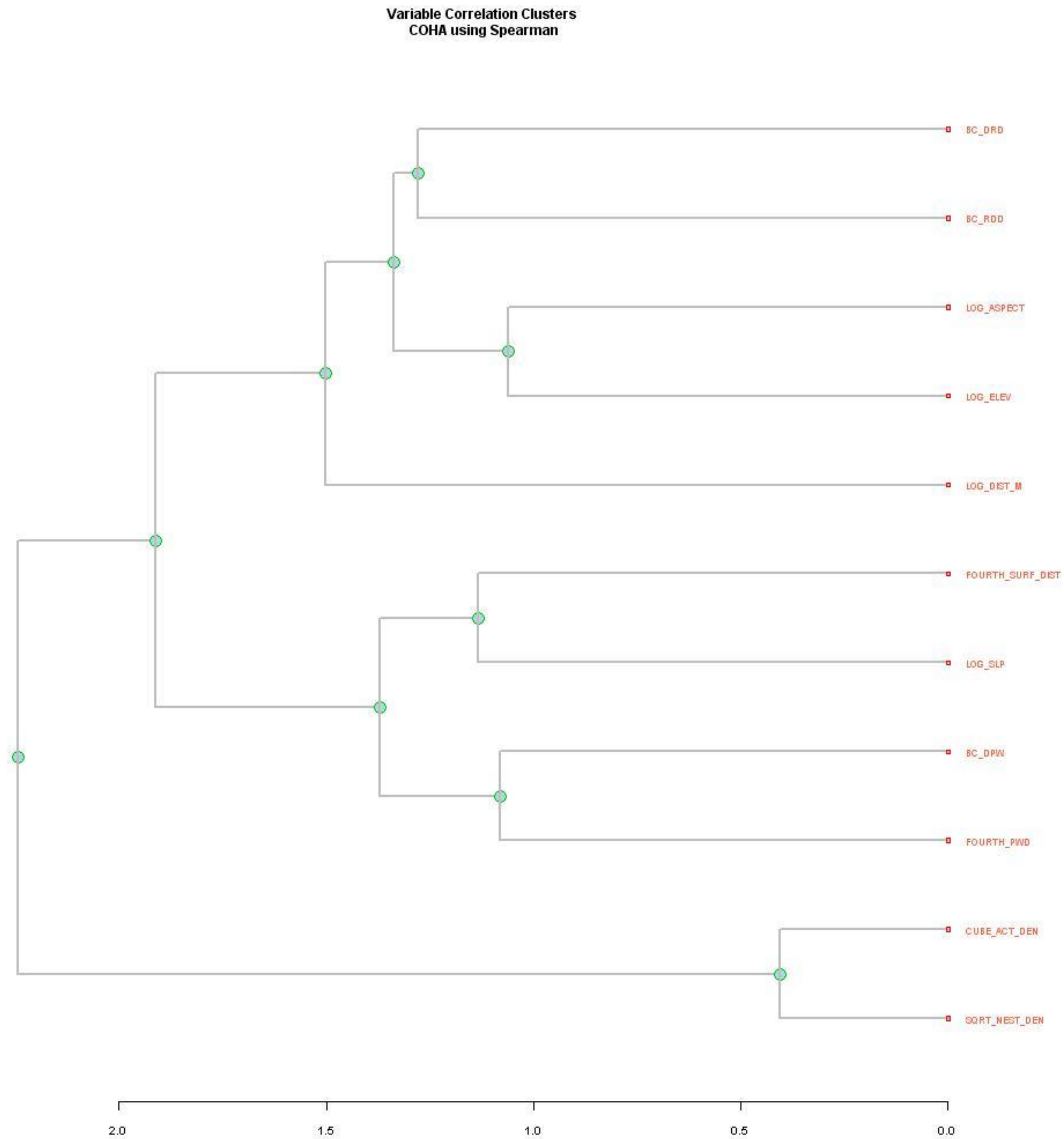


Figure 10. The above figure illustrates the degree of correlation between the response variables among occupied *Cooper's hawk* nests. The data used in this analysis were transformed. Moreover, because the data did not follow a normal frequency distribution, the Spearman correlation method was used.

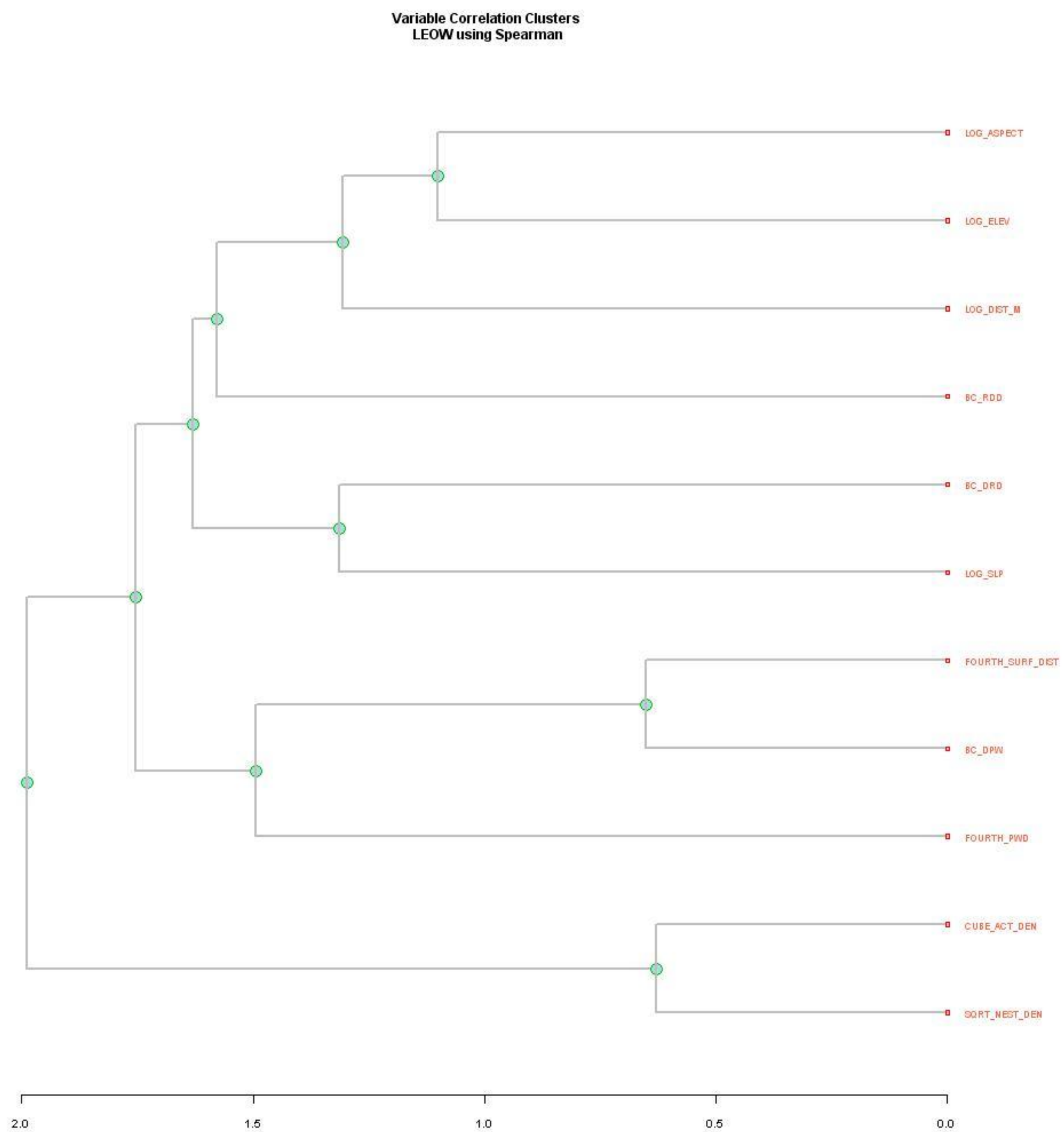


Figure 11. The above figure illustrates the degree of correlation between the response variables among occupied *Long-eared owl* nests. The data used in this analysis were transformed. Moreover, because the data did not follow a normal frequency distribution, the Spearman correlation method was used.

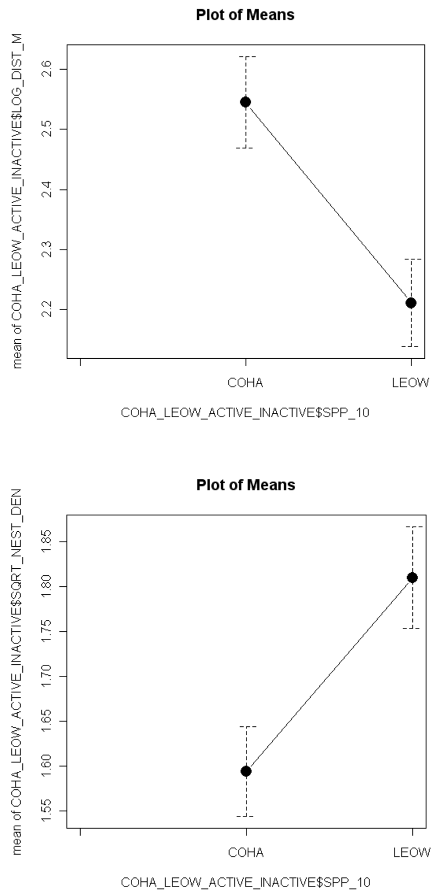


Figure 12. The figure above shows plots of the statistically significant relationships between response variables DIST_M (i.e., distance between nests, top figure) and NEST_DEN (i.e., nest density, bottom figure) and species (e.g., COHA versus LEOW), using single-factor, one-way ANOVA test procedures. For a list of applicable *p-value* scores, see Tables 13. The values represent mean values on the Log_{10} scale and the error bars are standard errors of the mean.

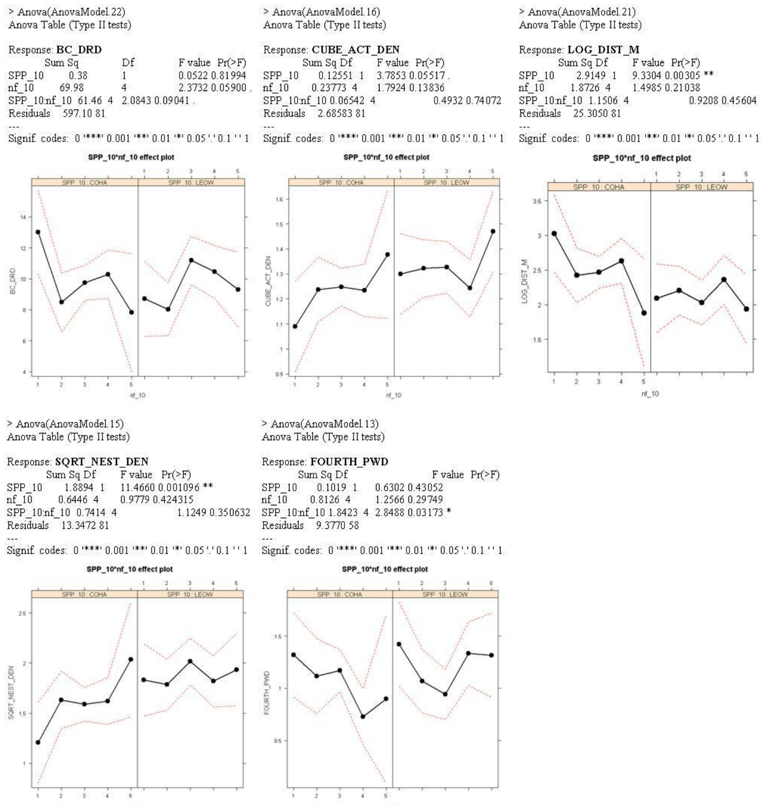
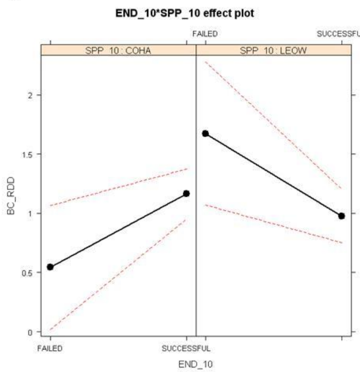


Figure 13. The figure above shows the two-way factorial ANOVA results comparing response variables to factor NF_10 (i.e., number of young that successfully fledged per nest; 5 levels: 1,2,3,4,5) and factor SPP_10 (i.e., raptor species; two levels: coha, leow). We recorded statistically significant relationships among the explanatory variables and response variables DIST_M (i.e., distance between nests), NEST_DEN (i.e., nest density), and PWD (i.e., producing well density). In addition, we noted interaction among the explanatory variables SPP_10 and NF_10 when comparing response variable means for producing well density (e.g., PWD).

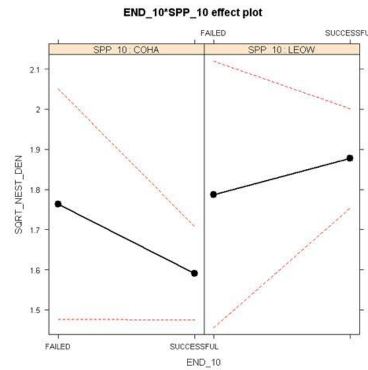
```
> Anova(AnovaModel.2)
Anova Table (Type II tests)

Response: BC_RDD
               Sum Sq  Df    F value  Pr(>F)
END_10          0.030   1    0.0538 0.817063
SPP_10          0.006   1    0.0109 0.917118
END_10:SPP_10   5.177   1    9.3058 0.002911 **
Residuals      56.743 102
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```



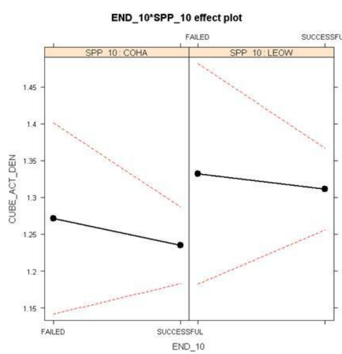

```
> Anova(AnovaModel.3)
Anova Table (Type II tests)

Response: SQRT_NEST_DEN
               Sum Sq  Df    F value  Pr(>F)
SPP_10         1.6760   1    9.9771 0.002086 **
END_10         0.0418   1    0.2485 0.619175
SPP_10:END_10  0.2048   1    1.2194 0.272075
Residuals     17.1347 102
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```




```
> Anova(AnovaModel.4)
Anova Table (Type II tests)

Response: CUBE_ACT_DEN
              Sum Sq  Df    F value  Pr(>F)
SPP_10        0.1456   1    4.2483 0.04183 *
END_10        0.0106   1    0.3081 0.58006
SPP_10:END_10 0.0008   1    0.0219 0.88251
Residuals     3.4947 102
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```




```
> Anova(AnovaModel.8)
Anova Table (Type II tests)

Response: LOG_DIST_M
               Sum Sq  Df    F value  Pr(>F)
SPP_10         2.9435   1    9.6974 0.002396 **
END_10         0.0358   1    0.1179 0.732007
SPP_10:END_10  0.2426   1    0.7991 0.373455
Residuals     30.9604 102
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

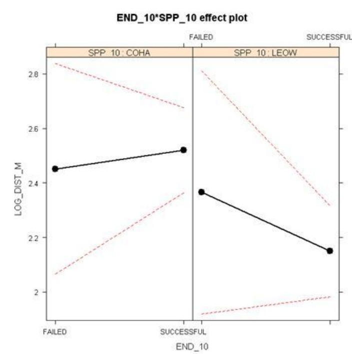


Figure 14. The figure above shows the two-way factorial ANOVA results comparing response variables to factor END_10 (two levels: successful and failed) and factor SPP_10 (i.e., raptor species, two levels: COHA and LEOW). We recorded statistically significant relationships among the explanatory variables and response variables RDD (i.e., road density), DIST_M (i.e., distance between nests), NEST_DEN (i.e., nest density), and ACT_DEN (i.e., active nest density). In addition, we noted interaction among the explanatory variables SPP_10 and NF_10 when comparing response variable means for producing well density (e.g., RDD).